WHAT DO SCIENTISTS HOPE TO LEARN WITH NASA'S MARS PERSEVERANCE ROVER?

HEARING

BEFORE THE

SUBCOMMITTEE ON SPACE AND AERONAUTICS

OF THE

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C O N T E N T S

April 29, 2021

WHAT DO SCIENTISTS HOPE TO LEARN WITH NASA'S MARS PERSEVERANCE ROVER?

THURSDAY, APRIL 29, 2021

HOUSE OF REPRESENTATIVES,
SUBCOMMITTEE ON SPACE AND AERONAUTICS,
COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY,
Washington, D.C.

The Subcommittee met, pursuant to notice, at 11:01 a.m., via Zoom, Hon. Don Beyer [Chairman of the Subcommittee] presiding.

SUBCOMMITTEE ON SPACE AND AERONAUTICS
COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY
U.S. HOUSE OF REPRESENTATIVES

HEARING CHARTER

What Do Scientists Hope to Learn with NASA's Mars Perseverance Rover?

Thursday, April 29, 2021
11:00 a.m.
Zoom

PURPOSE

The purpose of the hearing is to explore the science of the National Aeronautics and Space Administration's Mars 2020 Perseverance Rover mission, including key scientific objectives and plans, and overall Mars science exploration strategy, and other issues.

WITNESSES

- **Dr. Michael A. Meyer,** Lead Scientist, Mars Exploration Program, National Aeronautics and Space Administration
- **Dr. Bethany L. Ehlmann,** Professor of Planetary Science and Associate Director of the Keck Institute for Space Studies, California Institute of Technology; President, The Planetary Society; Co-Investigator, Mars 2020 Perseverance mission
- **Dr. Luther Beegle**, Principal Investigator of the Mars Perseverance Scanning Habitable Environments with Raman & Luminescence for Organics & Chemicals (SHERLOC) Instrument, Jet Propulsion Laboratory
- **Dr. Tanja Bosak**, Returned Sample Science Co-Lead, Mars 2020 Perseverance Rover; Professor and Lead of the Option in Geology, Geochemistry, and Geobiology, Department of Earth, Atmospheric, and Planetary Sciences, Massachusetts Institute of Technology

OVERARCHING QUESTIONS

- *What are the scientific goals of NASA's Mars 2020 Perseverance Rover mission?*
- *How do the Perseverance mission's scientific goals fit into the long-term objectives of NASA's Mars Exploration Program and the search for life beyond Earth?*
- *What is the scientific significance of Mars Perseverance's landing site in Jezero Crater?*
- *What are the new or enhanced capabilities and technology innovations on the Perseverance Rover, and how do they help enable the rover's science activities?*

BACKGROUND

On February 18, 2021, NASA's Perseverance rover touched down safely on the surface of Mars. Perseverance had traveled 293 million miles since launching on July 30, 2020 from Cape Canaveral in Florida on a United Launch Alliance Atlas V rocket. The NASA Mars 2020 Perseverance rover mission plans to spend at least one Martian year (687 Earth days) on the red planet, studying its geology and atmosphere, searching for signatures of past life, and preparing samples of surface material for eventual return to Earth for further study.

Perseverance[1] is the ninth U.S. spacecraft to successfully land on Mars, the fifth rover to successfully operate on the surface,[2] and the first mission that will collect samples on Mars for later return to Earth.

Mars

Mars is the fourth planet from the Sun. Like Earth, Mars is a terrestrial planet, made primarily of rock, though Mars is about half the size (by radius) and only about a tenth of the mass of Earth. The smaller mass means that gravity on Mars is about a third as strong as what we feel on Earth. With this relatively weak gravitational pull, and with no magnetic field to protect from the harsh solar wind, Mars cannot hold on to as much atmospheric material as the Earth. The Martian atmosphere of today is thin, with a density under one percent of the Earth's sea level atmospheric density. The atmosphere is approximately 95 percent carbon dioxide (CO_2) by volume at the surface.

A Martian day, or "sol," is 24.6 hours, though a Martian year is nearly twice as long as an Earth year, because Mars orbits about 50 percent farther from the Sun. Mars is tilted on its axis at nearly the same angle as the Earth is tilted. Therefore Mars, like Earth, also experiences seasonal, diurnal (night/day), and latitudinal variations in sun exposure, and thus has wind, weather, and temperature variations. For example, though the global average surface temperature is about -80°F, daytime temperatures near the equator can occasionally climb close to or even above freezing (32°F).[3]

Though the Mars of today is largely cold and dry, Martian geology and surface features show evidence of significant climate changes on geologic timescales; the planet may have gone through multiple ice ages, for example.[4] With evidence built from successive orbiting and

[1] The name "Perseverance" was given by seventh grader Alexander Mather, of Burke, Virginia, who submitted the winning entry to NASA's "Name the Rover" essay contest for the Mars 2020 Rover mission. https://www.nasa.gov/press-release/virginia-middle-school-student-earns-honor-of-naming-nasas-next-mars-rover.

[2] Successful U.S. Mars surface missions and launch dates: Viking 1 and 2, two landers (1975); Mars Pathfinder, lander and rover (1996); Mars Exploration Rovers, Spirit and Opportunity, two rovers (2004); Phoenix, lander (2007); Mars Science Laboratory, Curiosity rover (2011); InSight, lander (2018). Details available at: https://mars.nasa.gov/mars-exploration/missions.

[3] Smithsonian National Air and Space Museum, "Today, Mars is Warmer Than Earth. See How We Compare," January 5, 2018. Available at: https://airandspace.si.edu/stories/editorial/today-mars-warmer-earth-see-how-we-compare.

[4] Levy, Joseph S., et al., "Surface Boulder Banding Indicates Martian Debris-Covered Glaciers Formed Over Multiple Glaciations," Proceedings of the National Academy of Sciences, 118 (40, January 26, 2021. Available at: https://www.pnas.org/content/118/4/e2015971118.

surface missions, scientists have determined that, in the distant past, the surface of Mars was probably much warmer and much wetter,[5] and the atmosphere was also much thicker,[6] potentially providing conditions for liquid water on the surface at one point in Mars' history. Observations from the Curiosity rover, which continues to operate on Mars, showed that liquid water likely once flowed in at least some locations on the surface.[7] Further Curiosity measurements have found evidence that some locations on ancient Mars, at the same time as having liquid water present on the surface, also harbored the acidity (pH) and salinity conditions that scientists understand to be necessary for life.[8] Much of the ancient surface liquid water may be locked in minerals in the crust of the planet still today.[9] Water ice may also exist in large, concentrated quantities below the surface, and may even be potentially accessible by surface investigations.[10]

Top Priorities of Mars, Planetary Science Research

Every ten years, under the auspices of the National Academies of Sciences, Engineering, and Medicine, the U.S. planetary science community convenes to determine consensus priorities and recommendations for the most compelling science questions, and accompanying program elements, for the next decade of Solar System research and exploration. NASA is the primary funder of these planetary science "decadal surveys," and the recommendations are directed to NASA to guide the content of its planetary science portfolio.

The most recent decadal survey, *Vision and Voyages for Planetary Sciences in the Decade 2013-2022*,[11] identified three high-priority science goals of the exploration of Mars in the ensuing decade: determine if life ever arose on Mars, understand the processes and history of climate, and determine the evolution of the surface and interior. The committee identified the single highest-priority Mars science goal "to address in detail the questions of habitability and the potential origin and evolution of life on Mars," and found that sample return—that is, "analysis of carefully selected samples from geologically diverse and well-characterized sites that are returned to Earth for detailed study"—would have "significantly higher science return and a much higher science-to-dollar ratio" than further *in situ* rovers alone could in pursuit of that scientific goal.

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[5] Ramirez, Ramses M. and Craddock, Robert A., "The Geological and Climatological Case for a Warmer and Wetter Early Mars," *Nature Geoscience*, 11, pp 230-237, 2018. Available at: https://arxiv.org/abs/1810.01974.
[6] Jakosky, Bruce, "MAVEN Explores the Martian Upper Atmosphere," *Science*, Vol. 350, Issue 6261, p. 643, Introduction to Special Issue, November 6, 2015. Available at: https://science.sciencemag.org/content/350/6261/643.
[7] Skibba, Ramin, "History of Mars' Water, Seen Through the Lens of Gale Crater," *EOS,* April 5, 2018. Available at: https://eos.org/articles/history-of-marss-water-seen-through-the-lens-of-gale-crater.
[8] NASA, "NASA Rover Finds Conditions Once Suited for Ancient Life on Mars," March 12, 2013. Available at: https://www.nasa.gov/mission_pages/msl/news/msl20130312.html.
[9] Andrews, Robin George, "Where Did Mars' Liquid Water Go? A New Theory Holds Fresh Clues," *National Geographic,* March 16, 2021. Available at: https://www.nationalgeographic.com/science/article/where-did-mars-liquid-water-go-new-theory-holds-fresh-clues.
[10] Dundas, Colin M., et al., "Exposed Subsurface Ice Sheets in the Martian Mid-Latitudes," *Science*, Vol. 359, Issue 6372, pp. 199-201, January 12, 2018. Available at: https://science.sciencemag.org/content/359/6372/199.
[11] National Research Council. 2011. *Vision and Voyages for Planetary Science in the Decade 2013-2022*. Washington, DC: The National Academies Press. https://doi.org/10.17226/13117.

The decadal survey recommended that the highest-priority planetary science flagship (large) mission of this decade should be the Mars Astrobiology Explorer-Cacher (MAX-C) and the first step in a sample return campaign. The MAX-C mission concept, described in the decadal survey as a partnership between NASA and the European Space Agency (ESA), evolved into NASA's Mars 2020 Rover, later named Perseverance.[12]

Perseverance Rover Mission

NASA initiated the development of the Mars 2020 Rover mission in 2013. The mission is part of the Exploration Program (MEP) of the Planetary Science Division (PSD) of NASA's Science Mission Directorate (SMD). The mission is managed for SMD by the Jet Propulsion Laboratory (JPL), a division of the California Institute of Technology (Caltech).

The Perseverance landing site, Jezero Crater, was selected in 2018, after a five-year process involving the mission science team and the broader planetary science community.[13]
Jezero Crater is 28 miles across and located just north of the Martian equator, fully within the impact basin of a much larger (750 miles across) crater left by a meteorite earlier in ancient Mars history. By studying observations made with satellites orbiting far above the surface, scientists see evidence of past water flow into Jezero Crater and observe a feature that may be an ancient river delta; these surface environments could have held the right conditions for microbes to survive.[14] Perseverance's instruments will collect data and samples to determine if those past conditions were habitable and if there are any signs of long-past life still there today.

Perseverance's primary mission is one Martian year, or 687 Earth days. The rover is spending its first few months on Mars conducting tests of its hardware, software, and systems to assess health and performance, while also studying the conditions and terrain of the actual landing location. Concurrently, the mission is conducting a technology demonstration of the Ingenuity helicopter. Following the technology demonstration and the rover's system checks, the full science campaign and sample collection activities will begin.[15]

Science Objectives

Perseverance has four science objectives, which reflect decadal survey priorities:

- Geology: Explore an astrobiologically relevant ancient environment on Mars to decipher its geological processes and history, including the assessment of past habitability.

[12] The midterm assessment of progress on the decadal found that this mission concept met the recommendation. National Academies of Sciences, Engineering, and Medicine. 2018. *Visions into Voyages for Planetary Science in the Decade 2013-2022: A Midterm Review*. Washington, DC: The National Academies Press. https://doi.org/10.17226/25186.

[13] NASA, "NASA Announces Landing Site for Mars 2020 Rover," 2018. Available at: https://www.nasa.gov/press-release/nasa-announces-landing-site-for-mars-2020-rover.

[14] Ehlmann, Bethany L., et al., "Clay Minerals in Delta Deposits and Organic Preservation Potential on Mars," *Nature Geoscience,* 1, pp. 355-358, 2008. Available at: https://repository.si.edu/bitstream/handle/10088/16530/200840.pdf?sequence=1&isAllowed=y.

[15] O'Callaghan, Jonathan, "The First 100 Days on Mars: How NASA's Perseverance Rover Will Begin Its Mission," *Scientific American,* February 18, 2021. Available at: https://www.scientificamerican.com/article/the-first-100-days-on-mars-how-nasas-perseverance-rover-will-begin-its-mission/.

- Astrobiology: Assess the biosignature preservation potential within the selected geological environment and search for potential biosignatures.
- Sample Caching: Demonstrate significant technical progress towards the future return of scientifically selected, well-documented samples to Earth.
- Preparation for Humans: Provide an opportunity for contributed Human Exploration and Operations Mission Directorate or Space Technology Program[16] participation, compatible with the science payload and within the mission's payload capacity. [17]

The science objectives will be pursued both by conducting *in situ* measurements and analyses with the instruments mounted on Perseverance and by collecting and storing samples of rocks and soil as it traverses the Martian surface.

Science Instruments

Perseverance carries seven competitively selected science instruments led by principal investigators from U.S. universities, JPL, Los Alamos National Laboratory, and institutions in Spain and Norway:

- Mastcam-Z is a camera system mounted to the mast of the rover. Its twin cameras are capable of taking high-definition video, panoramic color and three-dimensional images of the Martian surface and atmosphere, with a zoom functionality for distant and small targets.
- Mars Environmental Dynamics Analyzer (MEDA) is a suite of weather and environmental sensors to monitor air and ground temperatures, wind speed and direction, temperature, humidity, dust counts, and radiation.
- Mars Oxygen In Situ Resource Utilization Experiment (MOXIE) will collect carbon dioxide (CO_2) from the Martian atmosphere and use it to produce oxygen (O_2). MOXIE is a test model (1 percent scale) of the technology that future human astronauts on Mars could potentially use to make oxygen for breathing and rocket fuel.
- Planetary Instrument for X-ray Lithochemistry (PIXL) is mounted at the end of Perseverance's robotic arm, and it will get up close to use x-ray sensors to study rocks and soil textures and chemical elements at tiny scales (less than a millimeter).
- Radar Imager for Mars' Subsurface Experiment (RIMFAX) will use radar to map the geologic features below the surface (stratigraphy) where the rover sits. Depending on the material, the radar can penetrate as far as 30 feet down.
- Scanning Habitable Environments with Raman & Luminescence for Organics and Chemicals (SHERLOC) will look for signs of past microbial life in the fine-scale structure of minerals and organic molecules that it may find on the Martian surface using a laser and ultraviolet cameras and spectrometers. SHERLOC is mounted on the end of Perseverance's robotic arm with PIXL.

[16] Now the Space Technology Mission Directorate.
[17] Mustard, J.F., et al., "Report of the Mars 2020 Science Definition Team," 154pp., posted July, 2013, by the Mars Exploration Program Analysis Group (MEPAG). Available at: http://mepag.jpl.nasa.gov/reports/MEP/Mars_2020_SDT_Report_Final.pdf.

- SuperCam will use cameras and a laser spectrometer from the rover's mast to determine the chemical composition and fine-scale structure of rocks and soil on the Mars surface, in order to look for organic compounds that could contain the signatures of ancient life.

Figure 1 shows the seven science instruments on a digital rendering of Perseverance. The rover is approximately the size of a compact car; it is ten feet long (not including the fully extended robotic arm), nine feet wide, and seven feet tall, and weighs 2,260 pounds. The rover body and configuration are based on that of NASA's Mars Science Laboratory Curiosity rover, which landed on Mars in 2012. All data collected by the science instruments, including measurements, images, videos, and sound recordings, are transmitted from radio antennae on Perseverance to NASA and ESA satellites orbiting Mars. The more powerful antennae on the orbiters then relay the data back to Earth through the Deep Space Network.

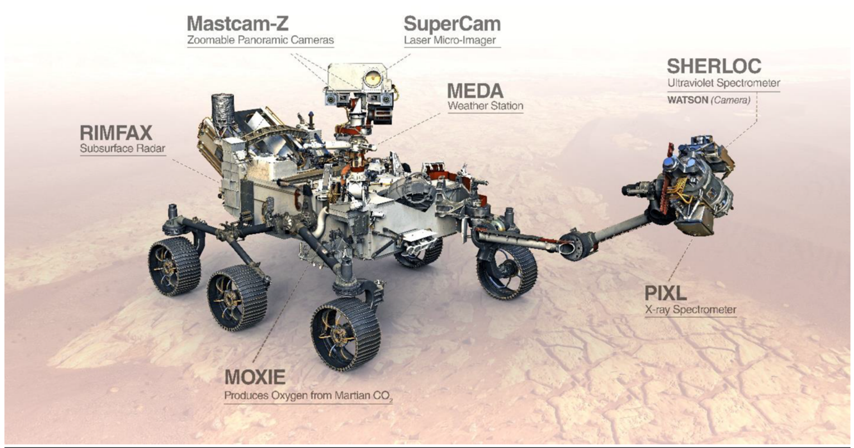

Figure 1. Science Instruments on NASA's Perseverance Mars Rover (digital rendering). Credit: NASA/JPL.[18]

Sample Collection

In addition to conducting investigations, the scientific instruments will help in identifying candidate rocks and soil for sample collection. A drill is mounted on the large robotic arm on the front of the rover (where PIXL and SHERLOC are also mounted), while all of the rest of the tools and supplies for the actual collection and storage of samples are in the "belly" of the rover, the underside between the wheels. This includes drill bits, 43 sample tubes, and a small robotic arm that will transfer sample tubes back and forth between the storage area in the belly of the rover and the large robotic arm. There are also five "witness tubes," which will each be opened, one at a time, to simply "witness" the environment around the rover by being put through the

[18] Available at: https://mars.nasa.gov/resources/25045/science-instruments-on-nasas-perseverance-mars-rover/.

steps of sample collection without actually collecting any sample, simply capturing any ambient exhaust or outgassing from the rover itself, to later be compared with the samples.

Once a sample has been taken, the tube is returned to the belly of the rover, sealed, and then stored safely until the mission science team determines where on the surface they wish to deposit one or more samples for eventual retrieval by the notional second stage of the Mars Sample Return campaign.

NASA, in collaboration with ESA, has been formulating a concept for a Mars Sample Return campaign to follow Perseverance with missions to retrieve the collected samples and return them to the Earth for study. In December 2020, NASA approved the campaign to enter the first phase of mission development for concept and technology development, notionally targeting a launch date of 2026.[19]

[19] NASA, "NASA Moves Forward with Campaign to Return Mars Samples to Earth," December 17, 2020. Available at: https://www.nasa.gov/press-release/nasa-moves-forward-with-campaign-to-return-mars-samples-to-earth.

Chairman BEYER. It's 11:01, this hearing will come to order. Without objection, the Chair is authorized to declare recess at any time. And before I deliver my opening remarks, I want to note that today the Committee is meeting virtually, and therefore I want to announce a couple of reminders to the Members about the conduct of this hearing. First, please keep your video feed on as long as you are present in the hearing, even if you need to go get a peanut butter and jelly sandwich. Just leave the video on and come back. Members are responsible for their own microphones. Also, please keep your mike muted unless you are speaking. Finally, if Members have documents that they wish to submit for the record, please e-mail them to the Committee Clerk, whose e-mailing address was circulated prior to the hearing.

So, good morning. Welcome to our witnesses. Thank you for being here. On February 18, just a few months ago, millions of people waited as the Mars Perseverance rover dove through the Martian atmosphere at speeds of 12,000 miles per hour. It implemented a complex sequence of operations, leading to the rover's safe landing in Jezero Crater. The cheers upon confirmation of the rover's successful arrival lifted us as a nation after a year that had tried us like no other. I just want to take a minute to celebrate and thank the people who got us to this point. Completing development, assembly, launch, and then landing, all while navigating the challenges of the COVID–19 pandemic, is a shining example of the tireless dedication of the NASA (National Aeronautics and Space Administration), Jet Propulsion Laboratory (JPL), and partner teams, so I want to thank them all for embracing the spirit of perseverance. And speaking of the name Perseverance, I want to give a plug to Alexander Mather, a middle student from Burke, Virginia who won the naming contest for the Mars 2020 rover with the very apropos name Perseverance.

Today we pivot our attention from launch and landing to science and discovery. Joining us here today are a group of experts who, no doubt, will whet our appetites for science as Perseverance prepares to explore the remains of an ancient lake and delta in Jezero Crater and search for signs of past life. Perseverance's work isn't the beginning of a scientific journey, it's a continuation of NASA's systematic robotic exploring—exploration of the red planet that started over 50 years ago with the Mariner flybys in the 1960's and the Viking landers in the 1970's. And I still remember so clearly those photos. Perseverance is now the fifth U.S. rover and the ninth U.S. landing craft—spacecraft to carry out science operations on Mars-achievements that, to date, only the United States can claim.

But next month China will attempt its first landing of a spacecraft that will descend from the Tianwen–1 spacecraft orbiting Mars. NASA spacecraft and others from the United Arab Emirates, India, and Europe are also in orbit around Mars, but make no mistake, Perseverance is a first. It's seeking what some might consider the holy grail of Mars science, samples that will be collected, stored, and returned by a future mission to Earth for scientific analysis. A 2007 National Academies report recommended that the highest-priority science objective for Mars exploration must be the analysis of a diverse suite of appropriate samples returned from carefully selected regions on Mars. And in 2011, the National Academies recommended the first step in a Mars sample return campaign as the highest priority large-scale planetary science mission. Perseverance's instruments and the samples it will collect will allow scientists to trace the evolution of Martian climate, geography, and the nature and complexity of any detected organic material. Martian samples could also tell us more about our own place in the Universe and our own very being.

Scientists tell us that when stars exploded in death, they dispersed new elements throughout the universe, elements including carbon, oxygen, nitrogen, which happen to comprise our own makeup, and that explains that we're made of this very stardust. Will Perseverance give us the opportunity to see images of our elemental selves in Martian dirt? Armed with multiple cameras and seven sophisticated science instruments, Perseverance is about to begin the return on the years of hard work and investment in the Nation's most advanced Mars rover to date. That return is sure to bring scientific discoveries about Mars, its habitability for past life, insights and knowledge to help us prepare for sending humans there, and the inspiration that propels our Nation to dream big, and our scientists, engineers, mathematicians, and future explorers to embrace ambitious challenges.

I have to confess that one of my favorite books is the *Red Mars, Blue Mars, Green Mars* series from Kim Stanley Robertson, and would recommend anybody watching in the hearing or on C–SPAN–3 to go buy it and read it right away. And I hope that our witnesses will continue to give us hope about the future of the human beings on Mars.

[The prepared statement of Chairman Beyer follows:]

Good morning, and welcome to our witnesses. Thank you for being here.

On February 18th, just a few months ago, millions of people waited as the Mars Perseverance rover dove through the Martian atmosphere at speeds of 12,000 miles per hour and implemented a complex sequence of operations leading to the rover's safe landing in Jezero Crater.

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NASA spacecraft and others from the United Arab Emirates, India, and Europe are also in orbit around Mars.

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I look forward to our witness' testimony.

Chairman BEYER. So I look forward to our witness' testimony, and I now recognize my friend, and the Ranking Member of the Space Subcommittee, Dr. Brian Babin of Texas. Dr. Babin?

Mr. BABIN. Yes, sir. Thank you, Mr. Chairman, and thank you to all these great witnesses that we're about to hear. NASA's planetary science missions exemplify the American spirit of exploration. They continue our very long tradition of our Nation of discovery and scientific inquiry. Missions like Perseverance expand humanity's reach throughout the solar system, inspire the next generation of explorers, and maintain technological expertise that is so important to our Nation's economic and national security.

Our Nation once again experienced a collective 7 minutes of terror as the Perseverance rover descended to the Martian surface 2 months ago. It will continue our long history of searching for evidence of past life, produce oxygen on the Martian surface, and has also demonstrated the very first controlled flight on another planet with our helicopter Ingenuity. Perseverance builds on the success of the Curiosity rover that landed on Mars nearly a decade ago, and the Spirit and Opportunity original landings in 2004, not to mention the 1976 Viking landing, the 1997 Pathfinder landing, and the Sojourner rover, and the more recent Phoenix and Insight landing. The landers were also enabled by spacecraft like Mariner, Mars Global Surveyor, Mars Odyssey, Mars Reconnaissance Orbiter, and the Maven spacecraft.

So far the United States is the only Nation to successfully land and operate on the red planet. To be more specific, the Jet Propulsion Laboratory is the only entity to do so successfully. Other nations have tried, and the Soviet Union has even landed, but no other nation has landed and operated for more than a few seconds. But even we have experienced failures. With all of our success, it is easy to forget that landing on Mars is a very hard task. We were reminded of this in the 1990's with the loss of the Mars Observer, the Mars Climate Orbiter, and the Mars Polar Lander. Despite these losses, we remained undeterred.

Going forward, other nations continue to explore Mars. Europe and Russia still operate the Trace Gas Orbiter around Mars. India's Mars Orbiter Mission entered Mars orbit in 2014, and the United Arab Emirates Hope mission, and China's orbiter and rover entered Mars orbit in February. We also expect another Russian and European ExoMars mission, and a Japanese Mars/Moon exploration mission in a couple of years. Mars is getting busy, and crowded, and for lots of reasons. Other nations see the benefit of planetary exploration, and Mars exploration in particular. Aside from the technological advantages of Mars exploration, some nations, particularly China, see this as a way to legitimize the Communist Party's leadership. Debates about prohibitions on cooperation with China are also coming to light as China prepares to land its own rover on Mars. Cooperation is always a tricky subject when it comes to space, and Mars is no different.

The Obama Administration canceled the ExoMars partnership with Europe because of cost overruns with the James Webb Space Telescope. That pushed Europe to partner up with Russia for that mission. As Mars exploration becomes increasingly international, Congress and the administration will have to carefully weigh the pros and cons of partnerships, and the impact of those partnerships on technology transfer and theft, national security, human rights, and Communist Party legitimacy. It is a privilege to partner with the world leader in exploration, and they might have more to gain from partnering with us than we do with them.

I look forward to many more exciting discoveries as we embark on a future planetary mission to Mars, like the bold sample return mission. NASA's Planetary Science Program balances a vast portfolio of missions from large, medium, and small sizes, and explores all of our solar system, including the outer planets, asteroids, and hopefully even a return to Venus in the future. I also look very much forward to understanding how big ticket items like the Mars Sample Return mission, the Europa Clipper mission, reconstituting the Nancy Grace Roman Telescope under the Astronomy Division, as significantly expanding the Earth Science Division, and how it will impact the agency and other programs.

Thank you very much for our witnesses for appearing today, and I look forward to your fascinating testimony. So, with that, I'll yield back, Mr. Chairman.

[The prepared statement of Mr. Babin follows:]

NASA's planetary science missions exemplify the American spirit of exploration. They continue our long national tradition of discovery and scientific inquiry. Missions like Perseverance expand humanity's reach throughout the solar system, inspire the next generation of explorers, and maintain technological expertise that is so important to our nation's economic and national security.

Our nation once again experienced a collective "7 minutes of terror" as the Perseverance rover descended to the Martian surface two months ago. It will continue our long history of searching for evidence of past life, produce oxygen on the Mars surface, and has already demonstrated the first controlled flight on another planet with Ingenuity.

Perseverance builds on the success of the Curiosity rover which landed on Mars nearly a decade ago, as well as the Spirit and Opportunity rovers landings in 2004, not to mention the 1976 Viking landing, the 1997 Pathfinder landing and Sojourner rover, and the more recent Phoenix and Insight landing. The landers were also enabled by spacecraft like Mariner, Mars Global Surveyor, Mars Odyssey, Mars Reconnaissance Orbiter, and the MAVEN spacecraft

So far, the United States is the only nation to successfully land and operate on the red planet. To be more specific, the Jet Propulsion Laboratory, is the only entity to do so successfully. Other nations have tried, and the Soviet Union even landed, but no other nation has landed and operated for more than a few seconds. But even we have experienced failures. With all of our success it is easy to forget that landing on Mars is hard. We were reminded of this in the 1990s with the loss of the Mars Observer, the Mars Climate Orbiter, and the Mars Polar Lander. Despite these losses, we remained undeterred.

Going forward, other nations continue to explore Mars. Europe and Russia still operate the Trace Gas Orbiter around Mars, India's Mars Orbiter Mission entered Mars orbit in 2014, and the United Arab Emirates' Hope mission and China's orbiter and rover entered Mars orbit in February. We also expect another European and Russian ExoMars mission and a Japanese Mars Moon Exploration mission in a couple years.

Mars is getting busy, and for lots of reasons. Other nations see the benefit of planetary exploration, and Mars exploration in particular. Aside from the technological benefits of Mars exploration, some nations, particularly China, see it as a way to legitimize the Communist Party's leadership. Debates about prohibitions on cooperation with China are also coming to light as China prepares to land its rover on Mars. Cooperation is always a tricky subject when it comes to space, and Mars is no different. The Obama Administration cancelled the ExoMars partnership with Europe because of cost overruns with the James Webb Space Telescope, which pushed Europe to partner with Russia for the mission. As Mars exploration becomes increasingly international, Congress and the Administration will have to carefully weigh the pros and cons of partnerships, and the impact of those partnerships on technology transfer and theft, national security, human rights, and communist party legitimacy. It is a privilege to partner with the world-leader in exploration, and they might have more to gain from partnering than we do.

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Thank you to our witnesses for appearing today, I look forward to your fascinating testimony.

Chairman BEYER. Mr. Babin, thank you very much. And with that, I'm going to recognize the Ranking Member of the Full Committee, Mr. Lucas, for an opening statement.

Mr. LUCAS. Thank you for holding this hearing, Mr. Chairman. When NASA's Perseverance rover landed on Mars in February, and became the eighth craft to successfully land on the Martian surface in a little over 40 years, every one of these vehicles were American made, and each of these explorers built on the technology and scientific knowledge gained from the craft which came before it.

Dr. MEYER. I can't hear anything.

Mr. LUCAS. Perseverance——

Dr. MEYER. Can anybody hear me?

Mr. LUCAS [continuing]. An ambitious mission, continues this legacy of innovation. The vehicle is searching for signs of ancient life as we speak, and it's helping us gain a better scientific understanding of the red planet. In addition to its scientific mission, Perseverance is helping us demonstrate new technologies, which will help aid future exploration of other planetary bodies, both through robotic and human missions.

A few weeks ago we saw the launch of a small helicopter named Ingenuity, which made the first powered flight on another planetary body, which has now made three more flights, each lasting longer, and traveling greater distances. In addition, Perseverance includes a technology demonstration called MOXIE. The instrument's purpose is to take the Martian atmosphere, which is mostly carbon dioxide, and create breathable air. The first demonstration was successful, producing more than 10 minutes of breathable air for an astronaut. Later, Perseverance will collect several samples of Martian soil, which will be left on the Martian surface. These samples will eventually be retrieved by a future mission and return to Earth for research. There are many other cutting edge and inspiring facets to Perseverance, each of which are laying the groundwork for future crewed exploration of Mars.

Though the U.S. has demonstrated unique leadership in Martian exploration, we're not the only ones interested in exploring the solar system. In the weeks leading up to Perseverance's landing a craft managed by the United Arab Emirates entered orbit. Additionally, another craft made by China entered orbit, the first vehicle from that country to do so. In the coming months China will attempt to be the second country to join the U.S.

Dr. MEYER. Would you like me to——

Mr. LUCAS [continuing]. In successfully landing a rover on Mars. This comes little more than 2 years after China first successfully landed a craft on the far side of the Moon, and only months after China became the second country to successfully return samples of lunar surface to the Earth. Less than 12 hours ago China launched the first module of a new space station, which it hopes to have completed by the end of next year. With these recent moves, the Chinese Communist Party has all but declared its intent to challenge U.S. leadership in space. These recent examples serve as stark reminders of why we need to avoid complacency in our space program. We must be mindful of this as our Committee considers how best to increase investments in basic research and develop a new generation of STEM (science, technology, engineering, and mathematics) participants.

We have seen repeatedly the power of NASA's missions to inspire future generations. I was pleased by the Biden Administration's public support for the continuation of the Artemis Program, which will return American astronauts to the lunar surface this decade and lay the groundwork for future human exploration of Mars. Now Congress must do our part and ensure that NASA has the resources and the direction it needs to execute this mission. I want to thank our witnesses for being here today and sharing their experiences working on this inspiring mission. I look forward to hearing ways this Committee could then continue to inspire future generations. Thank you, and I yield back my time, Mr. Chairman.

[The prepared statement of Mr. Lucas follows:]

Thank you for holding this hearing, Mr. Chairman.

When NASA's Perseverance rover landed on Mars in February, it became the eighth craft to successfully land on the Martian surface in a little over 40 years. Every one of these vehicles were American made and each of these explorers built on the technology and scientific knowledge gained from the craft which came before it.

Perseverance's ambitious mission continues this legacy of innovation. The vehicle is searching for signs of ancient life as we speak, and it's helping us gain a better scientific understanding of the Red Planet.

In addition to its scientific mission, Perseverance is helping us demonstrate new technologies which will help aid future exploration of other planetary bodies, both through robotic and human missions. A few weeks ago, we saw the launch of a small helicopter named Ingenuity, which made the first powered flight on another planetary body. Ingenuity has now made three flights, each lasting longer and traveling greater distances.

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In the coming months, China will attempt to become the second country to join the U.S. in successfully landing a rover on Mars. This comes little more than two years after China first successfully landed a craft on the far side of the Moon, and only months after China became the second country to successfully return samples of the Lunar surface to Earth. Less than 12 hours ago, China launched the first module of a new space station which it hopes to have completed by the end of next year.

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I want to thank our witnesses for being here today and sharing their experiences working on this inspiring mission. I look forward to hearing ways this Committee can continue to inspire future generations. Thank you, and I yield back my time.

Chairman BEYER. Thank you, Mr. Lucas, very much. If there are other Members who wish to submit additional opening statements, your statements will be added to the record at this point.

[The prepared statement of Chairwoman Johnson follows:]

Good morning. Thank you, Chairman Beyer, for holding this hearing and giving us the opportunity to hear about the exciting science to be gained from NASA's newest rover on Mars.

I would also like welcome our witnesses and thank you for testifying. I expect that you are all working very hard supporting the early surface operations of the rover. Some of you may even be operating on "Martian time" to carry out your tasks, and I sincerely appreciate you taking the time to share your expertise with us today.

I have often repeated my belief that NASA is a crown jewel of the Nation's research and development enterprise. That is clearly evident in the Mars Exploration Program's deliberate, strategic approach to studying Mars, with new missions successively building on past successes and knowledge gained over time.

Those past missions made significant discoveries. Scientists have learned that liquid water probably flowed in many places on the surface of Mars, and that many of the conditions required to support life as we know it likely existed along with liquid water, at least in some places.

The Mars 2020 Perseverance mission, which addresses the consensus top priority of the National Academies' planetary science decadal survey for a large flagship mission, is poised to continue that record of achievement, and I am looking forward to exciting new scientific advances coming from that mission.

Perseverance's science mission will take the important leap from the question of "was it habitable?" to "was it inhabited?" as it investigates Mars and collects samples that will eventually be returned to Earth for detailed study.

I look forward to hearing more from our witnesses about the fundamental science they hope to conduct with Perseverance in geology, astrobiology, atmospheric science, volcanology, and minerology in addition to the applied science investigations that will provide critical measurements in support of eventual human astronaut-scientists on the surface of Mars.

Let me close by recognizing Perseverance as a testament to the incredible achievements that our scientific and engineering workforce can accomplish, even under the most trying of circumstances. In addition, I am proud of the tremendous public engagement I have witnessed with the NASA Mars program and the Perseverance mission. It proves once again the important role NASA's missions play in inspiring children and learners of all ages.

Thank you, and I yield back.

Chairman BEYER. Let me now move to our witness introductions. Our first witness is Dr. Michael Meyer, and Dr. Meyer is a Senior Scientist at NASA Headquarters in the Science Mission Directorate, and is the lead scientist for NASA's Mars Exploration, and for the Mars Sample Return programs. He also serves as the program scientist for the Mars Science Laboratory Curiosity mission. During his career at NASA Dr. Meyer's held many roles, focused on the study of life in the universe, including as a Senior Scientist for Astrobiology. His primary research interest is the microorganisms living in extreme environments, particularly the physical factors controlling microbial growth and survival. Dr. Meyer received his Bachelor of Science degree in Biology from Rensselaer Polytechnic Institute, and a Master of Science and a doctorate in Oceanography from Texas A&M University. Welcome, Dr. Meyer, and we will switch back to you——

Dr. MEYER. Can you——

Chairman BEYER [continuing]. In just a minute. I'm going to introduce the others, and then we'll start with you, Dr. Meyer.

Our second witness is Dr. Bethany Ehlmann, Professor of Planetary Science and Associate Director of the Keck Institute for Space Studies at Caltech. Dr. Ehlmann is co-investigator (Co-I) on the Mastcam-Z and the SHERLOC (Scanning Habitable Environments with Raman & Luminescence for Organics & Chemicals) instrument teams in the Mars 2020 Perseverance rover. She's also a member of the science team for the Spirit and Opportunity Mars Exploration Rovers, and an affiliate of the Dawn orbiter team during its exploration of the largest asteroid and dwarf planet Ceres. Dr. Ehlmann's research focuses on the minerology and chemistry of planetary surfaces, remote sensing techniques and instruments, astrobiology, and science policy and outreach. Her primary focus is unraveling Mars's environmental history and understanding water in the solar system. Dr. Ehlmann received her undergraduate degree from Washington University in St. Louis, a Master of Science and a doctorate in Geological Sciences as a National Science Foundation graduate fellow at Brown University. So welcome, Dr. Ehlmann.

Our third witness is Dr. Luther Beegle, Principal Investigator (PI) of the Mars Perseverance Scanning Habitable Environments with Raman and Luminescence for Organics and Chemicals, SHERLOC, Instrument at the Jet Propulsion Laboratory. As a principal scientist the Jet Propulsion Laboratory, Dr. Beegle is responsible for conducting NASA funded research as a PI and Co-I in planetary science, focusing on detection and characterization of organic molecules for the identification of potential biosignatures. Dr. Beegle received a Bachelor of Science in Physics and Astronomy from the University of Delaware, and a Master of Science and

Physics, and a doctorate in Astrophysics, from the University of Alabama at Birmingham. So welcome, Dr. Beegle, and I'm sure our president will be pleased to know we have a University of Delaware graduate here.

And our final witness is Dr. Tanja Bosak, a Professor of Geobiology at the Massachusetts Institute of Technology, and Returned Sample Science Co-Lead of the Mars 2020 Perseverance Rover. Dr. Bosak's research focuses on how microbial processes leave chemical, mineral, and morphological signals in sedimentary rock. Her lab uses research approach to explore to explore modern geochemical and sedimentological processes, interpret to the co-evolution of life in the environment during the first 80 percent of Earth's history, and look for signs of past life on Mars. Dr. Bosak received her undergraduate degree in Geophysics from the Zagreb University, and a doctorate in Geobiology from the California Institute of Technology. So welcome, Dr. Bosak.

So we will start with Dr. Meyer, and you each have 5 minutes. Dr. Meyer, floor is yours.

TESTIMONY OF DR. MICHAEL A. MEYER, LEAD SCIENTIST, MARS EXPLORATION PROGRAM, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Dr. MEYER. Thank you. Chairman Beyer, Ranking Member Babin, and Members of the Subcommittee, I am honored to appear before the Subcommittee to discuss Mars science, and the role the Perseverance rover plays in NASA's broader Mars exploration program. Mars has captured the public's imagination as the planet in our solar system most similar to Earth. Both planets formed 4.5 billion years ago, and are the only planets to have known to be able to support life. Nevertheless, this transformation over time to the present has followed dramatically different paths. By studying Mars, we can learn about our history as well.

NASA's Mars Exploration Program studies Mars as a planetary system in order to understand its extreme climate variation on different timescales, its history of geological processes that have shaped Mars through time, its potential to have hosted life, and its future exploration by humans. As we learned about Mars, the strategy has evolved from follow the water, to explore habitability, to seek signs of life, and has brought us to the threshold of sample return with the Perseverance mission.

Perseverance is the most sophisticated rover ever to have been sent to the red planet, with a name that embodies NASA's passion, and our Nation's capability to take on and overcome challenges. As such, Perseverance will contribute to all four of NASA's high level goals of Mars during this exploration. In addition, Perseverance will collect and carefully select rock and regular samples for a future return to Earth.

Perseverance has already achieved at least five firsts. Terrain relative navigation enabled the descending spacecraft to avoid hazards. Perseverance landed in a place too dangerous for previous missions to land, but with terrain relative navigation, we could, and we did. The helicopter Ingenuity was the first aircraft in history to make a powered and controlled flight on another planet, a true Wright Brothers moment. SuperCam captured the sounds of

Martian wind, and the first audio of laser zaps on another planet. The Mars Oxygen In-Situ Resource Utilization Experiment has extracted 99 percent pure oxygen out of the Martian atmosphere, a resource for future rockets and humans. And Perseverance is the first leg of a round trip to Mars by caching samples on the surface.

All of us get to ride with Perseverance. The Perseverance mission carries more cameras than any interplanetary mission in history. This has allowed NASA to watch its own mission land on another world, and for the public to share in the experience. We have accomplished much, and will continue to do so because of the Mars exploration program. NASA's Insight mission will spend its extended mission listening for Mars earthquakes. NASA's other rover, Curiosity, continues to make exciting discoveries during the climb up Mount Sharp, just now entering the sulfate unit, which is a window into the Mars history when the planet became cold and dry.

NASA is also studying Mars from orbit, with the Mars Reconnaissance Orbiter, MAVEN, Odyssey, with ESA's (European Space Agency's) Mars Express missions, expanding our understanding of the dynamic planet we see today. For example, the science community has been able to piece together the anatomy of the 2018 global dust storm, the storm that ended NASA's Opportunity mission. We now understand the probability and the progression of global dust storms and their effects, thereby reducing the risks of future missions.

As the program has brought us to the sample return, this will be the first time samples will be brought back from another planet. It involves three missions, and a close collaboration with the European Space Agency. Once back on Earth we can analyze the samples in ways we can't on Mars. We can use instruments too large and too complex to send to Mars, and we can save material for future generations. Using instruments that have not yet been invented, and addressing questions that no one has yet thought of. NASA's Mars Exploration Program continues to lead the world in learning about Mars, and developing the technology that allows us to delve deeper into the secrets of the red planet, making significant progress in its goals of searching for life, understanding Mars climate, understanding Mars geology, and preparing for human exploration.

I want to thank Congress for their steady and generous support of Mars science, and I would be happy to any questions—answer any questions that you may have. Thank you.

[The prepared statement of Dr. Meyer follows:]

National Aeronautics and
Space Administration

Hold for Release Until
Presented by Witness

April 29, 2021

Subcommittee on Space and Aeronautics
Committee on Science, Space, and Technology

U.S. House of Representatives

Statement by:
Dr. Michael A. Meyer
Mars Exploration Program Lead Scientist
Science Mission Directorate

117th Congress

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Chairman Beyer, Ranking Member Babin, and members of the Subcommittee, I am honored to appear before this Subcommittee to discuss Mars science and the role that the Perseverance rover plays in NASA's broader Mars Exploration Program.

NASA's Study of Mars

Mars has captured the public's imagination and has been the subject of science fiction for more than 140 years. As the one planet in our solar system most similar to Earth, Mars has captivated scientists as well. Mars provides an ideal landscape for understanding the early history of the solar system and how planets transform over time. The terrestrial planets Mercury, Venus, Earth, and Mars formed over 4.5 billion years ago from similar building blocks of minerals and elements. Yet, Earth and Mars are the only planets known to have been able to support life. Nevertheless, their transformation over time to the present has followed dramatically different paths. By studying Mars, we can learn about Earth's history as well.

NASA has studied Mars since the early days of the space age, starting with the first successful flyby of Mars by our Mariner 4 spacecraft in 1964. We have successfully conducted a number of Mars lander and rover missions, including Viking, Mars Pathfinder/Sojourner, Spirit, Opportunity, Phoenix, InSight, Curiosity and now, Perseverance.

We now know that Mars had rivers and large lakes and perhaps even a northern ocean. The history of Mars since this point is one of water lost, gradual loss of a significant portion of its atmosphere, and near-surface water turning into ice. Were the early wet conditions favorable for the emergence of life, and did this life persist if it did form? Microbial life on Earth that emerged early in its geological history occupies nearly every available niche that provides sufficient energy in the form of transportable nutrients, and even Earth's atmosphere currently bears the stamp of life, with most of the oxygen present in the atmosphere produced over time through plants. Likewise, methane in Earth's atmosphere is constantly replenished by a variety of biological sources. We have not yet found evidence of past or present life on Mars, or on any extraterrestrial body for that matter, although this fundamental question motivates our science missions like Perseverance.

NASA's Four High-Level Goals for Mars

NASA's Mars Exploration Program studies Mars as a planetary system in order to understand the formation and early evolution of Mars as a planet, the history of geological processes that have shaped Mars through time, the potential for Mars to have hosted life, and the future exploration of Mars by humans. The strategy has evolved as we have learned more about Mars and as more questions have arisen. We have gone from "Follow the Water" to "Explore Habitability" to "Seek Signs of Life."

NASA organizes its scientific exploration of Mars around four high-level goals: 1) life, 2) climate, 3) geology, and 4) human exploration.

Goal 1 - Determine if Mars Ever Supported Life: Mars and Earth may have been relatively similar worlds during their early histories, and because life arose relatively early on the Earth, we want to know whether life ever arose on Mars. The two objectives of the goal are to determine if environments having high potential for habitability and preservation of biosignatures contain evidence of either past or present life.

Goal 2 - Understand the Processes and History of Climate on Mars: There are fundamental questions about how the climate of Mars has evolved over time to reach its current state, the processes that have operated to produce this evolution, and whether the Martian atmosphere and climate reflect features that are universal to planetary atmospheres. This Goal is further divided into three objectives: A) Characterize the state of the present climate of Mars' atmosphere and surrounding solar wind environment, and the underlying processes, under the current orbital configuration; B) Characterize the history of Mars' climate in the recent past and the underlying processes under different orbital configurations; and C) Characterize Mars' ancient climate and underlying processes.

Goal 3 - Understand the Origin and Evolution of Mars as a Geological System: Scientists seek insight into the composition, structure, and history of Mars as a planet through deeper understanding of its surface and interior. Mars might once have hosted potentially habitable, Earth-like environments. This Goal is further divided into three objectives: A) Document the geologic record preserved in the crust and interpret the processes that have created that record; B) Determine the structure, composition, dynamics, and evolution of Mars' interior and how it has evolved; and C) Determine the manifestations of Mars' evolution as recorded by its two moons.

Goal 4 - Prepare for Human Exploration: Robotic flight missions can help prepare for potential crewed missions to the Mars system, and these precursor missions can "buy down" risk that is inherent to any mission by acquiring information that can be acted upon during design, implementation, and operation of future crewed missions. This Goal is further divided into four objectives: A) Obtain knowledge of Mars sufficient to design and implement a human mission to Mars orbit with acceptable cost, risk, and performance; B) Obtain knowledge of Mars sufficient to design and implement a human mission to the Martian surface with acceptable cost, risk, and performance; C) Obtain knowledge of Mars sufficient to design and implement a human mission to the surface of either Phobos or Deimos with acceptable cost, risk, and performance; and D) Obtain knowledge of Mars sufficient to design and implement sustained human presence at the Martian surface with acceptable cost, risk, and performance.

Perseverance Rover

Perseverance rover embodies the NASA – and the scientific – spirit of overcoming challenges. Getting the spacecraft to the launch pad during a pandemic, searching for signs of ancient life, collecting and caching samples, and proving new technologies on a harsh planet are no easy feat. Nor is a soft touchdown on Mars: only 50 percent of Martian landing attempts, by any space agency, have been successful.

Perseverance arrived at Jezero Crater on February 18, 2021, after a seven-month journey from Cape Canaveral, Florida, and seven minutes of terror as it successfully completed its entry, descent, and landing. Jezero Crater is a 28-mile-wide (45-kilometer-wide) basin located in the Martian northern hemisphere. Sometime around 3.5 billion years ago, a river flowed into a body of water in the crater about the size of Lake Tahoe, depositing sediments forming a delta. The Perseverance science team believes these ancient river delta and lake deposits could have collected and preserved organic molecules and other potential signs of microbial life.

Jezero Crater has interested the scientific community for many years, but it had always been too hazardous for landing. Thanks to new technologies developed in partnership with the Space Technology Mission Directorate (STMD) that enabled Perseverance to target its landing site more accurately and avoid hazards (including steep cliffs, sand dunes, and boulder fields) autonomously, the spacecraft safely touched down about 1.7 kilometers from its pre-planned landing location after a 471-million kilometer (293-million-mile) journey from Earth.

Perseverance is the most sophisticated rover NASA has ever sent to the Red Planet, with a name that embodies NASA's passion, and our Nation's capability, to take on and overcome challenges. As such, Perseverance will contribute to all four of NASA's high-level goals for Mars. It will collect carefully selected and documented rock and regolith samples for future return to Earth, search for signs of ancient microbial life, characterize the planet's geology and climate, and pave the way for future human exploration of Mars.

Two of Perseverance's science instruments play a particularly important role in the search for potential signs of past life: SHERLOC (short for Scanning Habitable Environments with Raman & Luminescence for Organics & Chemicals), which can detect organic matter and minerals, and PIXL (short for Planetary Instrument for X-ray Lithochemistry), which maps the chemical composition of rocks and sediments. The instruments will allow scientists to analyze these features together at a higher level of detail than any Mars rover has done before.

Perseverance will also be able to use some instruments to gather science data from a distance. Mastcam-Z's cameras can zoom in on rock textures from as far away as a soccer field, while SuperCam will use a laser to zap rock and regolith (broken rock and dust) to study their composition in the resulting vapor. RIMFAX (short for Radar Imager for Mars' Subsurface Experiment) will use radar waves to probe geological features underground. The Norwegian Defense Research Establishment (FFI) contributed RIMFAX to Perseverance.

Check-out of Perseverance

Perseverance's early images and sounds are part of a planned 90-sol (~92.5 Earth days) initial checkout period. The mission team is using this time to perform tests of all the rover's parts and science instruments to ensure everything – including the team – is ready for surface operations. For about 70 sols, the operations team will be working on Mars time, which means they will be setting their clocks to the Martian day, which, compared to Earth time, progresses 40 minutes every day. This allows them to respond quickly to any issue the rover may have during its workday and to make sure revised instructions are ready for the next sol.

The first readings from the SuperCam instrument have arrived on Earth. SuperCam was developed jointly by the Los Alamos National Laboratory (LANL) in New Mexico and a consortium of French research laboratories under the auspices of the Centre National d'Etudes Spatiales (CNES). Perched atop the rover's mast, SuperCam's 12-pound (5.6-kilogram) sensor head can perform five types of analyses to study Mars' geology and help scientists choose which rocks the rover should sample in its search for signs of ancient microbial life. The University of Valladolid in Spain provided calibration targets for the SuperCam instrument suite. The calibration target assembly contains rock, synthetic glass, and ceramic targets, which will calibrate SuperCam's instruments against materials of known compositions and spectral properties.

Early data from SuperCam tests – including sounds from the Red Planet – have been intriguing. SuperCam captured the sounds of Martian wind and the first audio of laser zaps on another planet. Some zaps sound slightly louder than others, providing information on the physical structure of the target rocks, such as its relative hardness. This information will be essential when determining which samples to cache and ultimately return to Earth through our groundbreaking Mars Sample Return Campaign, which will be one of the most ambitious feats ever undertaken by humanity.

The SuperCam team also received excellent first datasets from the instrument's visible and infrared (VISIR) sensor as well as its Raman spectrometer. VISIR collects light reflected from the Sun to study the mineral content of rocks and sediments. This technique complements the Raman spectrometer, which uses a green laser beam to excite the chemical bonds in a sample to produce a signal depending on what elements are bonded together, in turn providing insights into a rock's mineral composition. In another first, this is the first time an instrument has used Raman spectroscopy anywhere other than on Earth. Raman spectroscopy is going to play a crucial role in characterizing minerals on Mars. It will help us understand the geological conditions under which the rocks formed and detect potential organic and mineral molecules that might have been formed by living organisms.

Perseverance's Mars Environmental Dynamics Analyzer (MEDA), the next-generation weather package developed by STMD, has been taking daily weather measurements (weather, climate, surface ultraviolet radiation, and dust), wind speed being an important factor for permitting helicopter flights (mars.nasa.gov/mars2020/weather). The National Institute for Aerospace Technology through the Center of Astrobiology (INTA-CAB) in Spain provided MEDA to Perseverance. In addition, the Center for the Development of Industrial Technology (CDTI) in Spain provided the High-Gain Antenna (HGA) subsystem, which utilizes flight-spare equipment from the Mars Science Laboratory mission.

Much of the immediate science debate concerns whether the rocks in the immediate area are primarily of igneous or sedimentary origin, which can be difficult to discern until close-up observations can be made. Observations of the delta front off to the northwest of the rover show that the rocks there are almost undoubtedly sedimentary in origin, with cross bedding and other sedimentary layering, consistent with expectations of the delta environment seen from orbit and confirming that they will be a prime target for sampling. Furthermore, to support future exploration, the toaster-sized Mars Oxygen In-Situ Resource Utilization Experiment (MOXIE), provided by STMD, successfully converted some of the Red Planet's thin, carbon dioxide-rich atmosphere into oxygen on its first attempt to extract oxygen out of the Martian atmosphere.

Ingenuity

Perseverance also ferried several cutting-edge technology demonstrations to the surface of Mars – including the helicopter. On April 19, 2020, NASA's Ingenuity Mars Helicopter became the first aircraft in history to make a powered, controlled flight on another planet – a true Wright Brothers moment. With the Wright Brothers, there were only a photographer and a few others there to see the event. With Ingenuity, it beamed back its own images and Perseverance provided video of this historic flight from its nearby perch, the Jacob van Zyl overlook.

This is an amazing accomplishment, as flying in a controlled manner on Mars is far more difficult than flying on Earth. The Red Planet has significant gravity (about one-third that of Earth's) but its atmosphere is just one percent as dense as Earth's at the surface, equivalent to approximately 10 miles in altitude, making it very difficult to generate lift. During Martian daytime, the planet's surface receives only about half the amount of solar energy that reaches Earth during its daytime, and nighttime temperatures can drop as low as minus 130 degrees Fahrenheit (minus 90 degrees Celsius), which can freeze and crack unprotected electrical components.

To fit within the available accommodations provided by the Perseverance rover, the Ingenuity helicopter had to be small. To fly in the Mars environment, the rotor blades had to be large, but the helicopter had to be lightweight. To survive the frigid Martian nights, it had to have enough energy to power internal heaters. The system – its rotors, solar panels, electrical heaters, and its control systems – had to be in sync – making necessary trajectory changes around 500 times per second – to be successful. We will now attempt longer and more complex flights, building our detailed understanding of interactions with Mars' atmosphere and preparing for future missions that will take advantage of this understanding to explore in new ways, both for future robotic and future human missions to Mars.

Perseverance Will Help Pave the Way for Future Human Missions to the Moon and Mars

Among the future-looking technologies on the Perseverance mission that will benefit human exploration is Terrain-Relative Navigation. As part of the spacecraft's landing system, Terrain-Relative Navigation uses camera images and computer processing to identify known surface features and calculate a spacecraft's course based on the location of those features in reference models or images. This system is the main reason Perseverance can explore a place as interesting as Jezero Crater. It enables descending spacecraft to quickly and autonomously comprehend location over the Martian surface and modify trajectory to avoid hazards. This technology will provide invaluable assistance for both robotic and crewed missions landing on the Moon and Mars.

Perseverance has more autonomy on the surface than any other rover, including self-driving smarts that allow it to cover more ground in a day's operations with fewer instructions from engineers on Earth. This fast-traverse capability (courtesy of upgraded sensors, computers, and algorithms) can translate into more science over the length of the mission. What's more, it will make exploration of the Moon, Mars, and other celestial bodies more efficient for other vehicles.

In addition, Perseverance carries a technology demonstration called MOXIE. This instrument is expected to extract oxygen at least nine more times over the course of a Martian year from Mars' carbon dioxide atmosphere, demonstrating a way that future explorers might produce oxygen for rocket propellant as well as for breathing.

Perseverance will help us understand the atmospheric structure and the behavior of spacecraft at Mars with the Mars Entry, Descent, and Landing Instrumentation 2 (MEDLI2) package, developed by STMD, an upgraded version of the instrumentation flown on the Mars Science Laboratory entry capsule.

All of Us Get to Ride Along with Perseverance

The mission team draws inspiration from the name of its rover, with particular awareness of the challenges the entire world is experiencing at this time. With that in mind, the mission installed a special plate to honor the dedication and hard work of the medical community and first responders around the globe. The team hopes to inspire the entire world, and future explorers, to forge new paths and make discoveries on which the next generation can build.

The Perseverance mission also carries more cameras than any other interplanetary mission in history, with 19 cameras on the rover itself and four on other parts of the spacecraft involved in entry, descent, and landing. These cameras allowed NASA to watch its own mission land on another world for the first time, and the public also was able to experience what it is like to land on Mars.

As with previous Mars missions, the Perseverance mission makes raw and processed images available on the mission's website as soon as they are received. In addition, a microphone on SuperCam is listening to the wind on Mars and later will help scientists understand the properties of rocks the instrument is examining. You can also follow Perseverance's adventure on social media via @NASAPersevere and @NASAMars on Twitter and Facebook, and the hashtag #CountdownToMars.

Perseverance is the First Leg of a Round Trip to Mars

Perseverance is the first rover to bring a sample caching system to Mars that will package promising samples for return to Earth by a future mission. Jezero Crater was carefully selected as the site for Mars sample collection because it contains the remains of an ancient, partially eroded delta, which formed by flowing water entering a lake or a sea and dropping the sediment it was carrying (i.e., just like the Mississippi River delta here in the U.S.). This sediment could contain the remains of life, if it were there. On Earth, mud from a delta is an excellent target for material that has concentrated and can preserve information about the life that once existed there. Mars does not have liquid water today at its surface, so our best way of understanding the role of water in Martian processes is to study the geologic record of places where water once existed.

The rocks surrounding Jezero Crater consist of even older crustal rocks that formed at a time when we think life first arose on the Earth. These will be key to understanding the earliest part of Mars' geological history. The surface of Mars is currently inhospitable due to being cold and dry and constantly bathed in damaging cosmic and solar ultraviolet radiation, so it is not expected that Martian organisms could live today near the surface of Jezero Crater.

The Mars Sample Return (MSR) campaign is a joint project between NASA and the European Space Agency (ESA). Three missions are involved: 1) Perseverance will select and collect the samples, 2) ESA's small "fetch" rover will retrieve the samples and load them into NASA's Mars Ascent Vehicle (MAV) rocket that will launch them into Mars orbit, and 3) ESA's Earth Return Orbiter will capture the NASA sample container and fly it the rest of the way to Earth. In summary, NASA is leading the sample collection rover, the lander, the ascent vehicle, and the sample container, while ESA is leading the fetch rover, the sample transfer arm to get the samples to the rocket, and the Earth Return Orbiter.

The returned samples from Mars are expected to consist of rocks, regolith, dust and gas. The number of samples to be returned depends on what is discovered by the Perseverance sample-collecting activities and on the health of that mission, but it is anticipated to be in the range of 10-30 samples. The samples are about the size of your pinky or a stick of chalk, and the total amount of sample material to be returned will fit in a volume the size of a basketball. That will be enough material to carry out a wide range of scientific investigations on each sample.

Once the samples are here on Earth, we can examine them more precisely with instruments too large and complex to send to Mars, providing far more information about them than even the most sophisticated rover could. Returned samples will also tell us how Mars' surface conditions changed with time—a key factor in understanding when and how a planet may have hosted life.

Sample return missions are the "gift that keeps on giving" to future generations. Scientists are still making new discoveries today based on lunar samples brought back by the Apollo astronauts more than 50 years ago. Many of the discoveries from Apollo samples are being made today by scientists who were not even alive when those rocks came back, using instruments that had not been invented yet, and addressing questions that no one had thought of when humans returned from the Moon in 1972.

Similarly, the samples gathered by Perseverance and returned by MSR will pave the way for generations of future scientists. Students who are in pre-school through high school today will be part of the teams of scientists who work on the returned samples. If we are successful, their children and grandchildren will still be making discoveries from those samples long after they are retired.

NASA's Future Exploration of Mars

We are not done studying Mars. NASA's InSight mission will spend its extended mission listening for more marsquakes using its seismometer instrument, despite its drilling operations ending early due to low friction in the Mars subsurface. NASA's other rover on Mars (Curiosity) continues to make exciting discoveries during its gradual climb up Mount Sharp, the 3-mile-tall (5-kilometer-tall) mountain it has been exploring since 2014. The rover is just now entering the "sulfate" unit – expected to provide a window into Mars history when the planet became cold and dry.

NASA also is studying Mars from orbit with the Mars Reconnaissance Orbiter, Mars Atmosphere and Volatile EvolutioN (MAVEN), Odyssey, and Mars Express missions. In addition, NASA recently signed a Statement of Intent with three space agencies (the Canadian Space Agency, the Italian Space Agency, and the Japan Aerospace Exploration Agency) to establish a joint concept team to assess mission potential, as well as partnership opportunities, on a future orbital mission to prospect for ice and volatiles on Mars. In response to a recommendation from the National Academies of Sciences, Engineering, and Medicine (NASEM), NASA recently commissioned a Mars Architecture Strategy Working Group (MASWG) to conduct a detailed analysis of the science and mission needs for exploring Mars beyond the planned MSR mission. The MASWG report was published in November 2020 with a variety of recommendations, which NASA will consider.

Investments in technology and in research and analysis (R&A) have continued to provide improvements in our capabilities to explore and understand Mars. Technology boosts, developed in partnership with STMD, are exemplified by Perseverance's landing, going to an exciting place only becoming accessible with improvements made by Terrain Relative Navigation. For R&A, using data from multiple spacecraft, the science community has been able to piece together the anatomy of a global dust storm, such as the one in 2018 that ended the Opportunity mission. We now understand the probable frequency and the progression of a global dust storm and its effects in warming the Mars atmosphere, changing circulation, and enhancing the loss of water to space. Another recent example is the now-recognized importance of water being absorbed into the crust – another significant process removing water from the Martian atmosphere.

Conclusion

Mars continues to be a popular place in our solar system. The United Arab Emirates and China both sent missions to Mars in 2020, traveling the "road" to Mars with Perseverance. NASA's Mars Exploration Program continues to lead the world in learning about Mars and developing the technology that allows us to delve ever deeper into the secrets of the Red Planet, making significant progress on its goals: of searching for life, understanding Mars' climate and geology, and preparing for human exploration.

I would be happy to answer any questions you may have.

Dr. Michael A. Meyer
Lead Scientist for the Mars Exploration Program
NASA Headquarters

Michael Meyer is a Senior Scientist at NASA Headquarters in the Science Mission Directorate. He is the Lead Scientist for NASA's Mars Exploration and for Mars Sample Return Programs, responsible for the science content of current and future Mars missions. Dr. Meyer is also Program Scientist for the Mars Science Laboratory/Curiosity mission. In 2009, Dr. Meyer was awarded Exceptional Service Medal and the Presidential Rank Award for Meritorious Professional Service.

Dr. Meyer was the Senior Scientist for Astrobiology from 2001 to 2006. The Program, which is dedicated to the study of the life in the universe, started in 1997 with Dr. Meyer as the Discipline Scientist. Since 1993, Dr. Meyer managed NASA's Exobiology Program and from 1994 to 1997, was also the Planetary Protection Officer for NASA, responsible for mission compliance to NASA's policy concerning forward and back contamination during planetary exploration. Dr. Meyer was the Program Scientist for the 2001 Mars Odyssey mission, which was launched in 2001 and is still orbiting Mars, and for the Mars Microprobe mission (DS-2) and for two Phase I Shuttle/Mir experiments. He was detailed from the Desert Research Institute, University of Nevada, where he was an assistant research professor from 1989-97. From 1985 to 1989, he served as associate director and associate in research for the Polar Desert Research Center, Department of Biological Science, Florida State University. In 1982, he was a visiting research scientist at the Culture Centre for Algae and Protozoa in Cambridge, England.

Dr. Meyer's primary research interest is in microorganisms living in extreme environments, particularly the physical factors controlling microbial growth and survival. He has conducted field research in the Gobi Desert, Negev Desert, Siberia, and the Canadian Arctic. He is also a veteran of six research expeditions to Antarctica, to study microbial ecosystems in the McMurdo Dry Valleys (1985/87), investigate krill-phytoplankton relations (1978/81), and research primary productivity in the Weddell Sea (1977). His experience also includes two summers working as a treasure salvager off the coasts of Florida and North Carolina.

Dr. Meyer earned his Ph.D. and M.S. in oceanography from Texas A&M University (1985 and 1981) and his B.S. in biology from Rensselaer Polytechnic Institute (1974).

Chairman BEYER. Thank you, Dr. Meyer, very much. I promise you, we're all very excited about Mars science. Now let me introduce Dr. Bethany Ehlmann for her testimony.

TESTIMONY OF DR. BETHANY L. EHLMANN, PROFESSOR OF PLANETARY SCIENCE AND ASSOCIATE DIRECTOR OF THE KECK INSTITUTE FOR SPACE STUDIES, CALIFORNIA INSTITUTE OF TECHNOLOGY; PRESIDENT, THE PLANETARY SOCIETY; CO-INVESTIGATOR, MARS 2020 PERSEVERANCE MISSION

Dr. EHLMANN. Thank you. Chairman Beyer, Ranking Member Babin, Members of Subcommittee, I appreciate all of your work to support science and exploration, and thank you for the opportunity to appear today. Our team was thrilled February 18 when JPL delivered our one-ton rover to the surface of Mars. I'm going to focus on the big picture science questions answerable at Mars, and how we conduct our exploration, while my colleagues will discuss the instruments and sample return portion.

For me, and I think for many of us, there is just a DNA of exploration in us as humans. We're drawn to ask profound questions. Are planets like our Earth rare, or are they common? Is there life elsewhere in the universe? One of the reasons I study Mars among all solar system planets is that Mars is a linchpin to answering these questions.

The different fates of Earth-like worlds in our solar system are recorded on Earth, Venus, and Mars. But what's special about Mars is that there's a vast rock record that spans the interactions of the interior of the planet, the atmosphere, the climate that record what makes a planet habitable over its first billion years. I draw the Subcommittee's attention to the Mars Architecture Strategy Working Group Report from November that goes far more deeply than I can in 5 minutes on these questions, reviewing the findings of our program, reaffirming the priority of sample return, and identifying how to move forward in the next decade about the interaction between science—scientific exploration, human exploration, and the growing commercial space sector, because, as was mentioned, it's an exciting time right now at Mars, 11 operating spacecraft from five different agencies.

So what does Perseverance do? Perseverance is both a science mission, like past rovers, and it's the first step in an ambitious three mission sequence to return samples to Earth. We've already accomplished a number of our technology goals, so what remains is to study the region's history, climate, look for signs of life. We act as a robot geologist, but I now want to move to my slides that I have, because we have a wealth of data from the Mars Exploration Program, and if we go ahead and move on to the first time step, I can talk about why this is important, and what we have learned, and what we will learn.

What I'm showing here is a hill-shaped topography map of Mars, because Mars today is a cold, dry desert, like the Antarctic dry valleys. Two decades of exploration, though, have discovered thousands of outcrops of rock across the surface. Everywhere you see a colored dot on this image, it's a mineral that formed in the presence of water. Some clay minerals, like you form in soils, some from aquifers underground, some salts. Now, there are thousands of places to explore, but we have gotten to a handful of them so far. You can see the Perseverance rover site is in a concentration of these exciting rock outcrops west of the Isidis Basin.

If we zoom in to where we have chosen to go with this Mars 2020 rover on the next slide, what we see here is beautiful, 45 kilometer, Jezero Crater. I hope, if you look to the—particularly to the left of Jezero Crater, what's exciting is that there is a landscape of 4-billion-year-old rocks. Particularly in the lower left you can see a series of rock mesas and outcrops, erosion planing off the historical record of Mars conveniently for us to drive through. And indeed the white dot is where we are right now on Mars. The white line is a notional traverse that we hope to undertake over the next 2 years.

In Jezero Crater, you can see it's a bit special. Over to the east there's an outflow channel. That's where water once drained out. To the north and to the west, there's an inflow channel that once drained in, and this is where Jezero Crater once had a lake. If we zoom in to the west, you can see this beautiful delta landform. Here I'm showing false color infrared data from one of the orbiters, the Mars Reconnaissance orbiter in our Exploration Program. The yellows and the purples are volcanic formed minerals. The greens are clay and carbonate. Clay and carbonate rocks are water formed. If you were on Earth, you would go to them to find the fossils.

If we go to the next slide it highlights, you know, just the amazing Mars coordinated Exploration Program, snapping our descent to the surface, with the HiRISE (High Resolution Imaging Experiment) instrument seeing Perseverance land at this landform that we worked for 20 years to find as the target of our exploration. I'll end with the final graphic, which is hot off the presses from the Mastcam-Z instrument, and really, I hope, reveals the tantalizing detail of what's to come. You can see the sands and the rocks of our landing site, the distant crater rim 10 kilometers away that we will eventually climb out on, but not before exploring these sediments and deposits ahead of us, so it's a rubbly landscape, and we've got to just make the first decisions about how to drive through it.

But as we finish off here, you see the mesas of the delta coming into view, those rocks that record the history of the lake. We're going to drive up to them with our instruments, sample them to select the best ones to bring back to Earth. So I look forward to reporting on our findings in the years to come.

[The prepared statement of Dr. Ehlmann follows:]

Statement of
Dr. Bethany L. Ehlmann
Professor of Planetary Science and Associate Director of the Keck Institute for Space Studies,
California Institute of Technology
President, The Planetary Society
Co-Investigator, Mars 2020 Perseverance mission

before the
Subcommittee on Space and Aeronautics
Committee on Science, Space and Technology
U. S. House of Representatives
29 April 2021
Hearing entitled:
What do Scientists Hope to Learn with NASA's Mars Perseverance Rover?

Chairman Beyer, Ranking Member Babin and members of the Subcommittee, thank you for your work to support science and exploration and thank you for the opportunity to appear today to discuss our exploration of Mars and what we hope to learn with NASA's Mars-2020 mission and the Perseverance rover.

I have worked for 15 years in planetary science, most extensively on Mars orbiter and rover missions, and am focused on the study of water, habitable environments, and the search for life in our solar system. I now have the privilege of being a member of the Mars-2020 Perseverance Science team as a Co-Investigator on the Mast Camera Zoom (Mastcam-Z) and Scanning Habitable Environments with Raman and Luminescence for Organics and Chemicals (SHERLOC) instruments.

Our science team was thrilled February 18, 2021 when the Jet Propulsion Laboratory team successfully delivered our 1-ton rover to the surface of Mars. My teammates and colleagues Dr. Luther Beegle and Dr. Tanja Bosak will speak on instrument development and science enabled by sample return. I focus my testimony on important science questions answerable at Mars, the goals of our Perseverance science team for exploration at Jezero crater, and why this is a special site for sample return. I offer also a few thoughts on the United States' Mars Exploration Program, how it enables us to ask and answer big questions, and why this is important for the future.

Answering the Biggest Questions at Mars with the Mars Exploration Program
As we peer into the vast universe with telescopes and have begun to discover Earth-like worlds around other stars, we're drawn to ask profound questions: And are planets like our Earth rare or common? And is there life elsewhere in the universe?

A linchpin to answering these questions is understanding the different fates of our solar system's 3 Earth-like worlds -- Earth, Venus, Mars -- and whether life existed or exists on them.

Of these, Mars is the only planet that still preserves an accessible, largely pristine record of its first billion years. Mars' vast rock record at the surface spans 4 billion years. It offers the longest term record of coupled, system-level changes in climate and habitability in our solar system that require coordinated exploration, as recently reviewed by the Mars Architecture Strategy Working Group report[1]. Mars has outstanding access to environments fundamental to the search for life; it is also the closest potentially habitable world to Earth and a key destination for future human exploration.

Two decades of a systematic Mars Exploration Program orbital mapping have shown how extraordinarily Earth-like Mars once was. Thousands of rock outcrops preserve a record of diverse environments, variable in space and time, much like Earth today. At same time the first life is preserved in Earth's fossil record (~3.5 billion years ago), Mars hosted lakes, rivers, shallow seas, Yellowstone-like hydrothermal systems, clay-rich soils, and underground aquifers of water[2].

Today Mars is a cold desert, like the Antarctic Dry Valleys. Understanding why its path was starkly different from Earth teaches us about the fundamental processes that create habitable environments, and why they endure (or not). Understanding whether Mars does or did host life teaches about the conditions of life's emergence and resilience.

Armed with our instruments and our questions, we have so far visited just a tiny handful of spots with landed missions. What we have found has answered some questions and deepened others. For example, the Spirit rover found a volcanic hydrothermal system, not seen from orbit. The Opportunity rover explored orbital signatures of crystalline iron oxides and discovered they originally formed beneath shallow acid lakes. The Curiosity rover's ongoing explorations at Gale crater have found evidence of a deeper lake with neutral-alkaline water chemistry as well as evidence of organic matter essential to life, tantalizing clues that confirmed Mars' past habitability. But was (is) Mars in fact inhabited?

Next missions: The Mars-2020 Perseverance Rover and Mars Sample Return
Perseverance seeks to answer this question. Perseverance is both a surface science mission, like past rovers, and the first step in an ambitious 3-mission sequence to return samples from Mars to Earth.

The Perseverance's Mission Objectives[3] are (1) to study the rocks and landscape at the landing site to reveal the region's history, (2) to determine whether an area of interest was suitable for life and look for signs of ancient life itself, and (3) to collect samples for possible future return to Earth. An additional objective looks to our future exploration: (4) to test technologies that would help sustain human presence on Mars someday.

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[1] Mars Architecture Strategy Working Group (MASWG), Jakosky, B. M., et al. (2020). Mars, the Nearest Habitable World—A Comprehensive Program for Future Mars Exploration. https://mepag.jpl.nasa.gov/reports/MASWG%20NASA%20Final%20Report%202020.pdf

[2] Ehlmann BL and CS Edwards (2014). Mineralogy of the Martian Surface, *Ann Review of Earth & Planetary Sciences*, 42, 219-315.

[3] Farley K et al. (2020) Mars 2020 Mission Overview. *Space Science Reviews*, 216(142) https://link.springer.com/article/10.1007/s11214-020-00762-y

The Perseverance rover has already accomplished several of its technology goals: measurement of detailed conditions during entry-descent-and-landing, successful use of onboard image-based terrain-relative-navigation to guide Perseverance to its safe spot in a rough field, the first production of oxygen from CO_2 in the Martian atmosphere by the Mars Oxygen In-Situ Resource Utilization Experiment (MOXIE) instrument, and on-the-ground weather measurement to compare with climate models. The team has flown a Mars helicopter, demonstrating the astounding feat of powered flight on another planet. The Ingenuity Mars helicopter lays the groundwork for future exploration technology, much as the 1997 technology demonstration Pathfinder rover laid the foundation for rovers to come.

Enabling Science: Sophisticated Instruments and Sample Caching for Return to Earth
Perseverance seeks the evidence of past life and past climate in rocks. Via textures, minerals, and chemicals the 4.5-billion year record can be teased apart to determine the relative importance of factors like a planet's size, its distance from the sun, whether it had an interior dynamo to generate a magnetic field, the history of volcanoes and tectonics, the composition of the atmosphere, the history of water, and the implications of these changes to life. The required measurements can only be made at the sub-meter and even sub-millimeter scales enabled by a landed mission.

One part of Perseverance's science is making select measurements "in the field" at Mars that one would typically perform in lab on Earth, like laser-induced breakdown spectroscopy (LIBS) and x-ray fluorescence for chemistry (XRF) and Raman spectroscopy for minerals and organics.

Our science team guides Perseverance to act as a robot geologist and geochemist, employing a strategy of nested scales of science observations from orbiter, to landscape, to outcrop, to millimeter. Right now, we're route-planning and debating two different paths our rover could take over the next several months. The science team makes decisions based on data from the Mastcam-Z instrument, which collects color and infrared images, and the SuperCam instrument, which collects remote data on mineralogy and chemistry. The Radar Imager for Mars' Subsurface Exploration (RIMFAX) uses radar to measure rock layers in the near subsurface. Together, data from these instruments guide our drive choices and help us decide which rocks and outcrops are most promising for a close look and a deeper investment of time.

Once adjacent to rocks, we direct Perseverance to use the instruments on its arm, the Planetary Instrument for X-Ray Lithochemistry (PIXL) and SHERLOC instruments, to make micrometer scale maps of texture, chemistry, minerals, and organics. Data from these instruments provide information on past volcanic activity, water chemistry, potential nutrients, and the processes which formed and shaped the rocks. With these data our team can also identify potential biosignatures down to sub-centimeter scale, pinpointing which samples are worthy of collection and addition to the cache for potential return to Earth.

Return of carefully selected samples from Mars to Earth has been a priority of the international planetary science community for decades[4]. Perseverance's samples would span diverse rock types not covered in the meteorite collection and be the first martian samples obtained with knowledge of their geological context and time order, which would allow us to measure isotopes and age date processes to trace the evolution of habitability. These samples would also allow us to search for microscopic-scale biosignatures, characteristic of Earth's earliest fossils, in ways not possible at the surface. In preparation for human exploration, it is also, frankly, prudent to demonstrate the technical ability to land, operate, and return to Earth.

Why Jezero? Landing and at the Right Spot

Succeeding in the quest to understand the changing habitability and search for life on Mars requires being at the right place with access to the right rocks recording the right time periods and environments. It took generations of geologists scouring all corners of the Earth to find Earth's oldest fossils. Armed with this experience, we chose a place on Mars that had multiple chances for preserving signs of past life, from different environments and different slices of Mars time, winnowing candidates from a field of dozens with data supplied by Mars Exploration Program orbiters. While returned samples from Perseverance would enormously advance our quest to understand habitability and the potential for past life on Mars, the reality is that the dozen finalists each captured a different epoch and environment, all potential habitats. There will remain more exploration after Perseverance.

The Jezero crater site offers the chance for an ambitious surface mission, rich with regions to explore, and a sample diversity worthy of our investment to bring them back. The 45-km diameter Jezero crater once held an open basin lake with two inlet valleys and outflow channel. The lake existed for thousands of years about 3 billion years ago. It preserves a prominent delta, a landform similar to that formed where the Mississippi River meets the Gulf of Mexico. Orbital infrared data show that the delta is enriched in clays, carbonates, and silica, some of the key minerals that preserve life and organic carbon on Earth.

Importantly, setting it apart from other Martian lakes, Jezero is located in one of best-preserved sequences of rocks from a still older epoch of Mars. Just outside of Jezero lie pieces of 4 billion year old layered igneous and sedimentary crust. Large mineral veins slice through this crust that were once part of an underground hydrothermal aquifer, now exhumed. These in turn are overlain by another igneous unit with discrete chemistry and still more waterlain rocks.

To a geologist, Jezero has two keystone stratigraphies for understanding Mars' evolution through time. In these rocks will be tiny inclusions that capture the composition of the Martian atmosphere and isotopes in mineral crystals that record the absolute ages of events. Its rocks preserve multiple types of habitats to search for biosignatures.

From the Octavia E. Butler Memorial Landing site, Perseverance will traverse the crater floor, collecting samples en route to the delta. There, it will search for deep lake sediments possibly

[4] Beaty D et al. (2019), The potential science and engineering value of samples delivered to Earth by Mars sample return. Report of the International MSR Objectives and Samples Team (iMOST), *Meteoritics & Planetary Science* 54, Nr S1, S3–S152

enriched in organics. Then, in the next year, Perseverance expects to climb the crater's rim and into the older mesas of the watershed, stepping backward in time. As it traverses, it will collect at least 20 samples for potential return to Earth. As early as 2026, NASA anticipates sending the next legs, a Mars Ascent Vehicle with Fetch Rover and Sample Return Obiter to return the rock samples to Earth.

Sustainability, Perseverance, Teamwork, and the Next Generation

For our Perseverance rover, while the excitement of landing has passed, the true work of the mission is just at the beginning for the science team. In our two-year primary mission, we will explore from our landing site on the floor to the Jezero delta and out to the ancient highlands, caching as we go. We expect to cross sand ripples, rough terrain, steep slopes. Our team will also have to make hard decisions: which routes do we take and which do we forego? which samples are most important and which are left? As we come to agreement -- and sometimes, inevitably, disagree but must nonetheless move forward -- we demonstrate a different sort of resilience and perseverance, a commitment to a mission larger than ourselves.

I came of age as a scientist and, in fact am a scientist, because of the Mars Exploration Program, which is a crown jewel of our nation's space enterprise. As an undergraduate student who was given the chance to be part of early Spirit and Opportunity science operations, I fell in love with the process of getting and interpreting new data from places never before seen. But it is in the interrelated data from multiple instruments and multiple sites where the true power lies. Over the past two decades, the sustained, forward-looking commitment of the Mars Exploration Program to a sequence of coordinated missions has led to seminal advances in understanding, not only Mars, but also how Earth-like planets work as systems[5]. Developing the science goals, developing science instruments and vehicle hardware, and selecting a landing site for Perseverance built on decades of knowledge of Mars exploration that required consistency of purpose -- endurance and perseverance. The Perseverance mission is only possible because of this sustained, strategic program and interconnected set of missions. Our strategy of doing the hard work to deepen our science questions with each successive mission of discovery, and of coordinating scientific and human exploration priorities, is a strategy that has paid off and one that will continue.

The choices for the Mars Exploration Program in the next decade will be pivotal. The European Space Agency (ESA) has stepped up in a major way to partner with NASA, leading multiple core elements that enable Mars Sample Return to happen now and to happen at reasonable cost. As articulated by independent review, science is mature and the technology is ready[6].

Right now there are 11 operating spacecraft in Mars from 5 different space agencies: NASA, ESA, India, China, and the United Arab Emirates. China's CSA will attempt a rover landing in

[5] Mars Architecture Strategy Working Group (MASWG), Jakosky, B. M., et al. (2020). Mars, the Nearest Habitable World—A Comprehensive Program for Future Mars Exploration.
https://mepag.jpl.nasa.gov/reports/MASWG%20NASA%20Final%20Report%202020.pdf
[6] NASA-ESA Mars Sample Return Independent Review Board and NASA response.
https://www.nasa.gov/sites/default/files/atoms/files/nasa_esa_mars_sample_return_final_report_small.pdf

May of this year. Increasing commercial launch capabilities and commercial technologies being leveraged in small satellites around Earth and in landers at the Moon are lowering the technical barriers and costs to entry that will enable more participants in Mars exploration.

The push to send humans to Mars stands at the cusp of reality with investments by NASA and the ambitions of commercial entities. For example, the vehicle recently awarded the contract for human lunar landers[7] had been developed for future Mars exploration. NASA's Mars Exploration Program is thus at a point where proponents of human and robotic exploration share many common aims and measurements and can benefit one another. Coordination between the scientific community (via structures such as the Mars Exploration Program Analysis Group and the National Academies), NASA leadership, international partners, and private sector stakeholders is key to create the teamwork to formulate the missions that effectively utilize limited resources and realize our shared ambitions.

Sample return, started with Perseverance, is the next scientific big step at Mars. But questions will remain after sample return. Other sites and past environmental types remain to be explored in the search for life and the quest to understand how, when and why Mars changed. Major questions remain about modern climate change on Mars and whether liquid water can and does ephermally exist on the surface or underground. And is there life on Mars today?

Growing up in Tallahassee, FL, I was a little kid who was always reading and whose parents fostered curiosity. From the plants, lizards, and frogs in my backyard to the almanacs, atlases, and National Geographic magazines stacked in a corner of our living room, weekly trips to the library, and a TV perpetually tuned to PBS, curiosity was encouraged. I embarked on a career in science and technology because I was inspired by exploration. Realizing in my teens that our nation was generating new knowledge each day from another planet and that I could be a part of this inspired me and has powered me through every tough moment of the long path to a Ph.D. and established career. I would love to see the U.S. commit to a continual landed presence on Mars; I would love to see operations centers for planetary missions at universities across the country. We inspire the next generation of explorers by introducing them early to the joy and teamwork of discovery.

I look forward to the coming decades as we continue our program of Mars Exploration to seek answers that help us answer the big questions, search for life, understand our own Earth's place in the cosmos, and inspire the next generation of explorers.

[7] Apr 16, 2021 RELEASE 21-042 As Artemis Moves Forward, NASA Picks SpaceX to Land Next Americans on Moon https://www.nasa.gov/press-release/as-artemis-moves-forward-nasa-picks-spacex-to-land-next-americans-on-moon

26 April 2021

Biography: Dr. Bethany L. Ehlmann
Professor of Planetary Science;
Associate Director of the Keck Institute for Space Studies,
California Institute of Technology

Prof. Ehlmann's research focuses on the mineralogy and chemistry of planetary surfaces, remote sensing techniques and instruments, astrobiology, and science policy and outreach. Her primary focus is unraveling Mars' environmental history and understanding water in the solar system.

Prof. Ehlmann is Principal Investigator of Lunar Trailblazer, a NASA smallsat mission with a goal to map the form, distribution, and abundance of water on the Moon and understand the lunar water cycle. She is a Deputy PI of the CRISM imaging spectrometer on the Mars Reconnaissance Orbiter, Participating Scientist on the Mars Science Laboratory Curiosity rover, Co-I on the Mastcam-Z and SHERLOC teams for the Mars 2020 Perseverance rover, and Co-I on the EMIT space station-based imaging spectrometer to explore Earth's dust source regions. She was also a member of the science team for the Mars Exploration Rovers (Spirit and Opportunity) and an Affiliate of the Dawn orbiter team during its exploration of the largest asteroid and dwarf planet Ceres. Prof. Ehlmann is working to propose instrument and mission concepts for Europa, Enceladus, Venus, the Moon, and asteroids.

In addition to her scientific research Prof. Ehlmann is active in policy and outreach. She presently serves as a member of the National Academies Committee on Astrobiology and Planetary Science and the Planetary Science and Astrobiology Decadal Survey 2023-2032 (Steering Committee member and Mars Panel vice-chair). She is President of the Planetary Society, the world's largest non-profit focused on fostering space exploration. In 2018, she authored a children's book on solar system exploration with Jennifer Swanson and National Geographic Kids, *Dr. E's Super Stellar Solar System*.

Prof. Ehlmann is an American Geophysical Union fellow, 2013 National Geographic Emerging Explorer, a former Mineralogical Society of America Distinguished Lecturer, and a recipient of the AGU's Macelwane medal, the American Astronomical Society Planetary Science Division Urey prize, and COSPAR's Zeldovich medal, as well as NASA Group Achievement Awards.

Prior to her appointment at Caltech, Prof. Ehlmann was a European Union Marie Curie Fellow at the Institut d'Astrophysique Spatiale, Orsay, France. Originally from Tallahassee, FL, she earned her undergraduate degree at Washington University in St. Louis, earned M.Sc. degrees from the University of Oxford in Environmental Change and Management and in Geography as a Rhodes Scholar, and earned her M.S. and Ph.D. in Geological Sciences as a National Science Foundation graduate fellow at Brown University.

Chairman BEYER. Dr. Ehlmann, thank you very much. Those look like mountains I would like to climb. Dr. Beegle, the floor is yours.

TESTIMONY OF DR. LUTHER BEEGLE, PRINCIPAL INVESTIGATOR OF THE MARS PERSEVERANCE SCANNING HABITABLE ENVIRONMENTS WITH RAMAN & LUMINESCENCE FOR ORGANICS & CHEMICALS (SHERLOC) INSTRUMENT, JET PROPULSION LABORATORY

Dr. BEEGLE. Chairman Beyer, Ranking Member Babin, and Members of the Subcommittee, I'm honored to appear before this Subcommittee on behalf of the California Institute of Technology to discuss the Mars Perseverance mission. On February 18, 2021 the Perseverance touched down in Mars' Jezero Crater. As we just saw, roughly about 3.5 billion years ago, Jezero Crater was the site of an ancient lake. Orbital images show that Perseverance has landed, in fact, right in front of what was once a river delta. Places like this can concentrate biologic activity, and are known to be excellent sources of preservation of organic molecules. We have high hopes for this location—what this location may hold for science.

All evidence points to Mars being more Earth-like in its early history, with rivers, lakes, and a large ocean potentially filling the southern hemisphere. At roughly the same time that life was starting on the Earth, water also flowed across the surface of Mars. We believe that many of the same conditions we think would be required for life on Earth were present on Mars at this time, including chemical energy sources and access to organic carbon.

On Earth many things have changed since life began a billion years ago. Key clues to the origin of life on our planet have largely been erased by weathering, erosion, and plate tectonics. On Mars, by contrast, there's little evidence of plate tectonics, and the surface has been less affected by these other processes, thus Mars is a much better preserved ancient rock record. Rocks on Mars could preserve key evidence of planetary formation, clues to its habitability, and potentially signs of macroscopic life.

Perseverance's payload has seven instruments that will analyze samples for future return to Earth. I am the principal investigator for an instrument called SHERLOC, which stands for Scanning Habitable Environments with Raman and Luminescence for Organics and Chemicals. SHERLOC was developed to search for clues with an astrobiology relevant mission and relevant environment on Mars. Starting soon, SHERLOC will identify—work to identify habitable environments, and see what we can do regarding Mars's history.

SHERLOC enables sensitive detection characterization and spatially resolved correlation of trace organic minerals and material within the Martian—within Martian outcrops. SHERLOC can identify potential biosignatures in the Martian surface and near subsurface. It does this by combining microscopic imaging and Raman and fluorescence spectroscopy to map a postage sized stamp of the Martian sample. Two microscopic cameras, the Autofocus and Confection Imager, or ACI, and the Wide Angle Topographic Sensor for Operations and Engineering, or WATSON, obtain high resolution images of the surface to identify textures and features smaller than 30 microns.

The Martian surface is an inhospitable for most organic molecules due to high ultraviolet radiation and oxidizing conditions. Perseverance has an abrasion tool to get to the protected interior of rocks, where organic molecules have been shown by NASA's Mars Science Laboratory, or Curiosity, to exist. Organic molecules that SHERLOC can identify are found in life as we know it, but a number of these have also been found in meteorites, or known to be created through abiotic chemical processes on the Earth. This is why we call any findings by SHERLOC potential biosignatures, rather than to claim—rather than claiming to have an instrument capable of unambiguous life detection.

Minerals can also be a form of biosignature. Biology can create distinctive signatures that can be observed in assemblages of astrobiology relevant materials. The presence of such assemblages in minerals in association with organics can be an important component in evaluating whether something may have been produced or brought about through biologic processes. SHERLOC will be looking for these types of features. The Mars 2020 mission is designed to collect well-characterized samples that have high scientific value. When these samples are eventually returned to Earth, they will be analyzed by state-of-the-art instruments, some of which cannot be flown to Mars for a variety of reasons. Some of these instruments have not even yet been invented. The combination of knowing where a sample came from, and multiple lines of evidence within that sample, should be able to get us closer to answering the tantalizing question of whether life existed, or ever—or exists on the next planet out from the Sun.

Finally, I have given many talks at schools focusing on the Mars 2020 mission, and SHERLOC in particular. I usually end those talks by reminding the students the samples we are collecting will be arriving back on Earth in the 2030's, that by pursuing a career in science and engineering, they can help answer the questions that we are currently waiting to answer. As we inspire the next generation of researchers, I imagine all the wonderful things that we will be able to accomplish, and all the big questions we will be able to answer from these samples. I would be happy to answer any questions you have.

[The prepared statement of Dr. Beegle follows:]

HOLD FOR RELEASE
UNTIL PRESENTED
BY WITNESS
April 29, 2021

Statement of
Dr. Luther Beegle
Principal Investigator, SHERLOC on Mars 2020
Principal Scientist
Jet Propulsion Laboratory

before the

Subcommittee on Space and Aeronautics
Committee on Science, Space, and Technology
U. S. House of Representatives

Chairman Beyer, Ranking Member Babin, and members of the Subcommittee, I am honored to appear before this Subcommittee on behalf of the California Institute of Technology to discuss the Mars Perseverance Mission.

The Mars 2020/Perseverance Mission

On February 18, 2021, the Perseverance rover touched down in Mars' Jezero Crater. Roughly 3.5 billion years ago, Jezero Crater was the site of an ancient lake. Rivers flowed both into and out of its basin over an extended period of time. Orbital imagery shows that Perseverance has in fact landed right in front of what was once a river delta. Places like this can concentrate biological activity and are known to be an excellent source of preservation of organic molecules, and we have high hopes for what this location may hold for science.

The Mars 2020 mission has four science goals: 1) Explore an ancient Martian environment of astrobiological relevance and decipher its geological processes and history, including past habitability; 2) Assess the biosignature preservation potential within that geological environment and search for them; 3) Make progress toward returning scientifically selected, well-documented samples from Mars to Earth; and 4) Provide an opportunity to contribute to future human missions to Mars.

Of course, inspiration is always part of the mission. Perseverance has captured the public's excitement and imagination through the images returned from the surface; the incredible videos of the entry, descent and landing phase; and, most recently, the highly anticipated flight of the Ingenuity helicopter. And we are only 68 sols, or Martian days, into our mission.

The Mars 2020 science team consists of nearly 500 individual researchers with experiences and backgrounds that range from undergraduate students to University professors to NASA Jet Propulsion Laboratory (JPL) experts who have worked every Mars rover mission since Mars Pathfinder/Sojourner in 1997. They have diverse scientific backgrounds in disciplines such as geology, climate, biology, and planetary science. It really is an amazing team and I am honored to be part of it.

Scientific Background

All evidence points to Mars being more Earth-like in its early history, with rivers, lakes, and a large ocean potentially filling its northern hemisphere. At roughly the same time when life was starting on Earth, water also flowed across the surface of Mars. We believe that many of the same conditions we think would be required for life on Earth were present on Mars, including a chemical energy source and access to organic carbon.

On Earth, many things have changed since life began several billion years ago. Key clues to the origin of life on our planet have largely been erased by weathering, erosion, and plate tectonics. On Mars, by contrast, there is little evidence of plate tectonics and the surface has been less affected by these other processes. Thus, Mars has a much better-preserved ancient rock record. Most rocks on the surface are thought to have been formed when Mars was warmer and wetter than we find it today. Rocks on Mars could preserve key evidence of planetary formation, clues to its habitability when liquid water was present, and, potentially, signs of microscopic life.

Today, Earth is the one and only planet where we have evidence of life's origin. From a scientific perspective, if we find that life originated on Mars, this raises the possibility that life could be abundant in the universe. Conversely, if we find the opposite, we might be able to better constrain the requirements for the origin of life and better explain how life originates on a planet. From a philosophical perspective, if life is plentiful in the universe, it might bring us new perspectives on ourselves and the universe. If life is rare, we might start to realize how unique and precious life is on Earth.

Building Instruments to Find Life

In order for any new instrument to be incorporated into a payload, it has to demonstrate scientific utility and technical feasibility. This process can take many years, decades even, and requires scientists and engineers to work together to generate an integrated and robust flyable concept. The development of an instrument concept is a process in which one experiences successes sprinkled with many rejections and failures. It also comes with no guarantee of ever getting a chance to fly on a mission.

Some astrobiology instrument concepts are not sensitive enough to detect the faint traces of life expected on Mars. Some concepts simply cannot function in the harsh and complex Martian environment. Finally, even with advances in technology, some concepts simply cannot be miniaturized to fit on a rover. There is no way to know at the beginning of development which concept will survive to flight. It is clear that it really does take perseverance to get to Mars.

SHERLOC

Perseverance's payload has seven instruments that will document the landing site and analyze samples for future return to Earth. I am the Principal Investigator for an instrument called SHERLOC, which stands for Scanning Habitable Environments with Raman & Luminescence for Organics & Chemicals. SHERLOC was developed to search for clues within an astrobiologically relevant environment on Mars. Starting soon, SHERLOC will work to identify habitable environments and see what we can deduce regarding Martian history. SHERLOC was selected through the 2013 announcement of opportunity for payload elements for the Mars 2020 rover. The proposal took a year to write and was one of seven selected from a pool of over 58 instrument concepts. The concept for SHERLOC was first conceived at JPL starting in 1998 and went through multiple stages of development until the flight unit was delivered in January of 2020.

SHERLOC enables high-sensitivity detection, characterization, and spatially-resolved correlation of trace organic material within Martian outcrops. SHERLOC can identify potential biosignatures in the Martian surface and near sub-surface. It does this by combining microscopic imaging with Raman and fluorescence spectroscopy to map a postage-stamp-sized Martian sample.

Two microscopic cameras, Autofocus and Context Imager, or ACI, and Wide Angle Topographic Sensor for Operations and eNgineering, or WATSON, obtain high-resolution images of the surface to identify textures and features smaller than 30 microns. Raman spectroscopy identifies organic, chemical, and mineral components present. Fluorescence spectroscopy detects and classifies organic molecules that have aromatic ring structures. It does so within a 100 micron-spot, roughly the same size as a human hair, that is moved over a surface. To assess the presence of potential biosignatures, SHERLOC makes mineral and organic maps. These are then analyzed by the science team to determine their astrobiological significance.

The Martian surface is an inhospitable place for most organic molecules due to high ultraviolet fluctuation and oxidizing conditions. Perseverance has an abrasion tool to get to the protected interior of a rock where organic molecules have been shown by NASA's Mars Science Laboratory/Curiosity to exist. The classes of organic material that SHERLOC is sensitive to include amino acids, nucleobases, and aromatic compounds. These molecules are found in life as we know it, but a number of these have also been found in meteorites or are known to be created though other abiotic chemical processes on the Earth. This is why we would call any findings by SHERLOC "potential biosignatures" rather than claiming to have an instrument capable of unambiguous life detection.

Minerals can also be a form of biosignature. Biology can create distinctive signatures that can be observed in assemblages of astrobiologically-relevant minerals (e.g., carbonates, nitrates, phosphates, sulfates). The presence of such assemblages of minerals in association with organics can be an important component in evaluating whether something may have been produced or brought about by biological processes. SHERLOC will be looking for these types of features.

As designed, SHERLOC specifically targets minerals and organics that are indicative of Jezero Crater's watery past. These minerals can also represent key sources and sinks for elemental cycling necessary for life. Life on Earth is driven by oxidation-reduction reactions and utilizes key elements such as carbon, hydrogen, nitrogen, oxygen, phosphorus, and sulfur. The abundance and diversity of compounds containing these elements in a sedimentary environment are important measures of habitability.

Working Toward Sample Return

As hard as I and others have worked on SHERLOC, the rest of our instrument suite and other instruments working on the Martian surface, it is hard to identify instruments or measurements that could unambiguously identify life on a Martian sample at present. After all the work we have – and will – put into Perseverance, the best way to unambiguously determine whether life was ever present within Jezero Crater will still be to return samples to Earth. To that end, the Mars 2020 mission is designed to collect well-characterized samples that have high scientific value. When these samples are eventually returned to Earth, they will be analyzed by state-of-the-art instruments, some that cannot be flown to Mars. Some of these instruments have not even been invented yet. The combination of knowing where a sample came from and multiple lines of evidence within that sample should be able to get us closer to answering the tantalizing question of whether life exists, or ever existed, on the next planet out from the Sun.

Finally, I have given many talks at schools focusing on the Mars 2020 mission and SHERLOC in particular. I usually end those talks reminding the students that the samples that we are collecting will be arriving back on Earth in the 2030's. That by pursuing a career in science and engineering, they can help answer the questions that are currently waiting to answer. As we inspire this next generation of researchers, I imagine all the wonderful things we will be able to accomplish and all the big questions we will be able to answer.

I would be happy to answer any questions you may have.

CURRICULUM VITAE

Luther Beegle
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Phone: (818)-354-2400 Email: Luther.Beegle@jpl.nasa.gov

Education

University of Alabama at Birmingham	Ph.D.	1997	Astrophysics
A Model of the Complex Hydrocarbon Component of the Interstellar Medium: Observational and Experimental Considerations			
University of Alabama at Birmingham	MS	1995	Physics
University of Delaware	BS	1990	Physics/Astronomy

Present Position:

2016-present: Deputy Division Manager, Science.
2014-present: Principal Investigator, SHERLOC.
2015-present: Principal Scientist, Jet Propulsion Laboratory. Responsibilities include conducting NASA funded research as a PI and Co-I in planetary science focusing on detection and characterization of organic molecules for the identification of potential biosignatures.

Past Positions:

2013-2016: Deputy Section Manager, Planetary Science Section, Science Division at JPL.
- Supervised a section of ~80-100 Ph.D. scientists

2009-2018: Surface Sampling System Scientist MSL SASHaP system. Supported the development of the hardware testbeds and identified samples for ambient testing until MSL landed. Participation in scientific operations focusing on properties of surface material and the acquisition and processing of samples in Gale Crater.
2003-2015: Research Scientist, Jet Propulsion Laboratory, California Institute of Technology, Pasadena California. Responsibilities include conducting NASA funded research as a PI and Co-I in planetary science focusing on detection of organic molecules off in situ platforms.
2005-2013 Group Supervisor Group 3225, Planetary Chemistry and Astrobiology group, Science Research Division, Jet Propulsion Laboratory, California Institute of Technology.
- Supervised a research group of 8 to 15 Ph.D. scientists

2001-2003: Scientist, Jet Propulsion Laboratory, California Institute of Technology, Pasadena California. Conducted NASA funded research as a PI and Co-I on the collection, extraction, detection and identification of organic molecules as part of a future *in situ* rover platform.
1999- 2001: Postdoctoral Scholar, California Institute of Technology, Pasadena California Developing analytical instrumentation techniques for the *in-situ* search for organic molecules. Conducted astrobiological experiments to help elucidate conditions organic molecules might face on extraterrestrial planets.
1997- 1999: National Research Council Post-Doctoral Scholar, Jet Propulsion Laboratory, California Institute of Technology, Pasadena California. Performed first ever

temperature dependent absorption spectroscopy of atmospheric species. Performed electron impact studies on the atmospheric species of CO and SO_2.

1996: Instructor, PHS110, An Overview of Space Exploration, The University of Alabama at Birmingham.

1993-1997: Research Assistant, The University of Alabama at Birmingham, under NASA programs: Origins of Solar Systems, Exobiology, UV Astronomy, and IR Astronomy. Investigated interstellar molecules and ions which make up the interstellar medium and are responsible for several Astronomical features including the 2175 Å bump, Unidentified Infrared bands, and Diffuse Interstellar Bands (UV Astronomy, IR Astronomy and Origins of Solar Systems). Addition investigations included work on the miniaturization of a laser Raman spectrometer (PIDDP), and identification of carbonaceous material in ancient terrestrial rock samples as Martian Analogs (Exobiology).

1991-1993: Teaching Assistant, The University of Alabama at Birmingham. Taught Classical Mechanics laboratory for majors and non-majors, Thermodynamics for majors, Electricity and Magnetism for majors, and Modern Physics for majors.

Funded Proposals:

Scanning Habitable Environments with Luminescence and Raman for Organics and Chemistry: SHERLOC. An investigation on Mars 2020 to launch August 2020.

Principal Investigator *in 9 different proposals funded under three different NASA programs PIDDP, ASTID.*

Co-Investigator *on 19 peer-reviewed proposals which were funded under 7different NASA programs: ASTEP, MIDP, PIDDP, ASTID, Vision Missions, Origins of Solar Systems, Exobiology and UV/VIS Astrophysics.*

Funded Proposals (Task Manager Co-I):

Advanced Robotic Detection of Chemical/Biological Agents, Toxic Industrial Gases and IEDS for Force Health Protection PHASE II SBIR from the Army. Small Business point of contact: IonFinity*, LLC*. 2.5 years, $225K. 2008

Miniature Electric Sniffer for Navy Vertical Take-Off Unmanned Aerial Vehicle (VTUAVS) SBIR from the Army. Small Business point of contact: IonFinity*, LLC*. 2 years, $225K. 2008.

Professional Activities:

- Editor, *Astrobiology* Journal
- Member of a multi-center ad hoc committee (*Keeping the candle lit*) for future human exploration of Mars (2010-2013).
- Member of the American Association for the Advancement of Science, the International Society of Ion Mobility Spectroscopy, the American Geophysical Union, and the American Chemical Society.
- Member of the Astrobiology Science Steering Group to define Astrobiological objectives for future Mars missions (2004)
- Member of the Mars Human Precursor Science Steering group defining risks and measurements needed for human exploration of Mars (2005)
- Worked with the University of Alabama at Birmingham's Media Relations department as science expert for local interviews with television stations and newspapers.
- Worked with education outreach at University of Alabama at Birmingham as guest lecturer at local schools (elementary, middle and high).
- Judge for the Alabama Science Olympiad (1995, 1996, 1997).

- Reviewer for Planetary and Space Science, Astrobiology, Icarus, Earth and Planetary Science Letters, Journal of Geophysical Research and Analytical Chemistry
- Reviewer for NASA Mars Fundamental Research Program (2005)
- Organized topical sessions for The Geological Society of America Annual Meeting, Lunar and Planetary Science Conference, and the American Geophysical Union Fall meetings.

Mentor:

Post Doctorial Mentor for: Joseph Razzell Hollis, Brandi Carrier, Hugh Kim, Everett Salas, and DeLing Liu.

Abbreviated List of Summer Interns: Hanieh Amoozegar, Brett Beckett,Alexa Raquel Bilek, Andrew Carnes, Juliana Capri, Nathan Figlewski, Kristina Goltz, Benjamin Hall, Samuel Long, Hugh Kim, Ernest Ryu, Alison Saltzman, Shakher Sijapati, Santosh Soparawalla, Meagan Spencer, Saman Halabian

Patents:

- Proton-Transfer Reaction/Ion Mobility Spectrometer. Developed a novel high-pressure hollow cathode ionizer for use in ambient Martian environments. Patent number: 6,794,645 B2, 21 September 2004.
- Development of an automated de-salting apparatus. NPO 45428
- Non-Contact Conductivity Measurement for Automated Sample Processing Systems. Provisional Patent CIT-5831-P.

Publications:

SHERLOC:

Detection and Degradation of Adenosine Monophosphate in Perchlorate-Spiked Martian Regolith Analogue, by Deep-Ultraviolet Spectroscopy in Astrobiology

Mars 2020 Mission Overview in Space Science Reviews

An Optical Model for Quantitative Raman Micro-Spectroscopy in Applied Spectroscopy.

Attenuation of ultraviolet radiation in rocks and minerals: Implications for Mars Science in Journal of Geophysical Research: Planets

WATSON: In Situ Organic Detection in Subsurface Ice Using Deep-UV Fluorescence Spectroscopy in Astrobiology

Deep UV Raman spectroscopy for planetary exploration: The search for in situ organics in Icarus

Mars Science Laboratory:

A look back, part II: The drilling campaign of the Curiosity rover during the Mars Science Laboratory's second and third martian years. Icarus Deep-ultraviolet Raman spectra of Mars-relevant evaporite minerals under 248.6 nm excitation in Icarus

A Look Back: The Drilling Campaign of the Curiosity Rover during the Mars Science Laboratory's Prime Mission in Icarus

Uniaxial compressive strengths of rocks drilled at Gale crater, Mars in Geophysical Research Letters

ChemCam investigation of the John Klein and Cumberland drill holes and tailings, Gale crater, Mars in Icarus

A Habitable Fluvio-Lacustrine Environment at Yellowknife Bay, Gale Crater, Mars. Science

In Situ Radiometric and Exposure Age Dating of the Martian Surface in Science

MAHLI at the Rocknest sand shadow: Science and science-enabling activities in Journal of Geophysical Research-Planets

Collecting Powdered Samples in Gale Crater, Mars; An Overview of the Mars Science Laboratory Sample Acquisition, Sample Processing and Handling System in Space Science Reviews

Instrument/Mission Development:

X-Ray Emission from Jupiter's Galilean Moons: A Tool for Determining Their Surface Composition and Particle Environment in Astrophysical Journal

Effects of Hypervelocity Impact of Molecules from Enceladus' Plume and Titan's Upper Atmosphere on NASA's Cassini Spectrometer from Reactive Dynamics Simulations in Physical Review Letters

LIFE: Life Investigation for Enceladus: A Sample Return Mission Concept in Search for Evidence of Life in Astrobiology

Miniature Mass Spectrometer Equipped with Electrospray and Desorption Electrospray Ionization for Direct Analysis of Organics from Solids and Solutions. in International Journal of Mass Spectrometry

Particle Sieving and Sorting Under Simulated Martian Conditions in Icarus

Particle Transport and Distribution on the Mars Science Laboratory Mission: Effects of Triboelectric charging in Icarus

Mojave Mars Simulant – a New Approach to Martian Soil Simulants in Icarus

RASP Based Sample Acquisition of Analogue Martian Permafrost Samples: Implications for NASA's Phoenix Scout Mission in Planetary and Space Science

Ion mobility spectrometry in space exploration in International Journal of Mass Spectrometry

Chemistry

Time Resolved Studies of Interfacial Reactions of Ozone with Pulmonary Phospholipid Surfactants Using Field Induced Droplet Ionization Mass Spectrometry in Journal of Physical Chemistry B

Interfacial Reactions of Ozone with Surfactant Protein B in a Model Lung Surfactant System in Journal of the American Chemical Society

Structural Characterization of Phospholipids Using Traveling Wave Ion Mobility Spectrometry in N2 in Analytical Chemistry

An Experimental and Theoretical Investigation into the Correlation between Mass and Ion Mobility for Choline and Other Ammonium Cations in N_2 in Analytical Chemistry

Electrospray Ionization Ion Mobility Spectrometry of Carboxylate Anions: Ion Mobilities and a Mass-Mobility Correlation in Journal of Physical Chemistry A

Effects of Drift-Gas Polarizability on Glycine Peptides in Ion Mobility Spectrometry in International Journal of Mass Spectrometry

Investigation of Drift Gas Selectivity in High Resolution Ion Mobility Spectrometry with Mass Spectrometry Detection in Journal of the American Society for Mass Spectrometry

Electrospray Ionization High-Resolution Ion Mobility Spectrometry for the Detection of Organic Compounds, 1. Amino acids in Analytical Chemistry

Astrobiology

A concept for NASA's Mars 2016 Astrobiology Field Laboratory. Astrobiology The Cell and the Sum of Its Parts: Patterns of Complexity in Biosignatures as Revealed by Deep UV Raman Spectroscopy. Frontiers in Microbiology in

The Mojave Vadose Zone: A Subsurface Biosphere Analog for Mars in Astrobiology

Analysis of Underivatized Amino Acids of Geological Interest using Ion-Pairing Liquid Chromatography/Electrospray Ionization/Tandem Mass Spectrometry in Astrobiology

Astrophysics

Laboratory Investigation of the Contribution of Complex Aromatic/Aliphatic Polycyclic Hybrid Molecular Structures to Interstellar Ultraviolet Extinction and Infrared Emission in Astrophysical Journal

Hydrogenation of Polycyclic Aromatic Hydrocarbons as a Factor Affecting the Cosmic 6.2 Micron Emission Band in Spectrochimica Acta Part a-Molecular and Biomolecular Spectroscopy
Experimental Indication of a Naphthalene-Base Molecular Aggregate for the Carrier of the 2175 Angstrom Interstellar Extinction Feature in Astrophysical Journal Letters
A Laboratory Analog for the Carrier of the 3 Micron Emission of the Protoplanetary Nebula IRAS 05341+0852 in Astrophysical Journal
Plasma Processing of Interstellar PAHs into Solar-System Kerogen in Planetary and Space Science
Inference of a 7.75 eV Lower Limit in the Ultraviolet Pumping of Interstellar Polycyclic Aromatic Hydrocarbon Cations with Resulting Unidentified Infrared Emissions in Astrophysical Journal
Spectroscopy of PAH Species in the Gas-Phase in Planetary and Space Science

Aeronomy
Middle Ultraviolet and Visible Spectrum of SO2 by Electron Impact in Journal of Geophysical Research-Space Physics
High Resolution Emission Spectroscopy of the A (1)Pi-X (1)Sigma(+) Fourth Positive Band System of CO Excited by Electron Impact in Astronomy and Astrophysics
Electron-Impact Excitation/Emission and Photoabsorption Cross Sections Important in the Terrestrial Airglow and Auroral Analysis of Rocket and Satellite Observations in Physics and Chemistry of the Earth Part C-Solar-Terrestrial and Planetary Science
Temperature-Dependent photoabsorption Cross Section Measurements of O-2 at the NI Airglow and Auroral Emission Lines in Chemical Physics Letters

Full vitae, including publications, available upon request

Chairman BEYER. Dr. Beegle, thank you very much. And our grand finale, Dr. Bosak, floor is yours.

TESTIMONY DR. TANJA BOSAK, RETURNED SAMPLE SCIENCE CO-LEAD, MARS 2020 PERSEVERANCE ROVER; PROFESSOR AND LEAD OF THE OPTION IN GEOLOGY, GEOCHEMISTRY, AND GEOBIOLOGY, DEPARTMENT OF EARTH, ATMOSPHERIC, AND PLANETARY SCIENCES, MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Dr. BOSAK. Chairman Beyer, Ranking Member Babin, and Members of the Subcommittee, thank you so much for inviting us to share our delight with this mission so far. And it's really—it is great just to see you all excited about tomorrow's science.

Because—I think we are all excited because we are, just at the beginning of a truly exciting time with the landing of the Perseverance rover in Jezaro Crater that Bethany showed. We'll be able to identify and collect samples of rocks, soils, and minerals from this known location on Mars, and the return of the samples to Earth is likely to transform our views of planetary evolution, climate, habitability, and even the origin of life. And this is an ambitious endeavor, and one that will inspire the children of today to learn more about science and technology.

Why it's ambitious? Well, we are bringing samples back from Mars. But—not only that, but for the first time we really will dare to ask the question of whether these samples contain something that may have been life. We are looking for life on other planets, and this is a very old question. For millennia, in fact, people have wondered whether there is life outside of Earth, and how—and when life began, what conditions are necessary to get life started. And so far Earth is the only known planet with life. Scientists like myself find the early signs of life in some of the oldest sedimentary rocks in the Earth that are 3.5 billion years old. However, if you ask us how life began, we'll start hemming and hawing, and that's simply because we don't have the answer to that. We—nobody knows.

So to answer this, some scientists are trying to synthesize organic molecules that are presence in all living cells, and even make proto-cells in test tubes. Other scientists look at old rocks in the Earth, but there are few preserved rocks on Earth that are old enough to tell us what our planet even looked like more than 3.5 billion years ago, and this is where Mars comes in. It has this amazing history.

The Mars 2020 mission will collect more than 30 pencil sized samples of rocks and soils in and outside of Jezaro Crater, and many of these rocks are older than 3.5 billion years. They attest to a warmer Mars that contained liquid water at the surface. If those conditions lasted long enough, they may have supported microbial life. So, if—sample these rocks, and analyze them on Earth, we really can open the window into a time that we currently know little about.

So the samples from Mars have to be returned to Earth to be analyzed. We heard that already from Michael and Luther. The analysis to look for life in rocks, one has to cut them, one has to make thin slices of them to look through them, one needs the best microscopes because we are looking for microbial life. Everything that old has to be microbial. We also need other types of instruments to characterize the organic molecules that may be present, and all sorts of other chemicals, even to tell exactly how old those rocks are. We need different types of instruments. We simply cannot miniaturize all that and fit that many instruments in a single room.

So once the samples come back, scientists will analyze them for decades, just like they're still doing with the rocks brought back from the Moon by Apollo, and this was more than 50 years ago. The analysis of Martian samples would determine how and when different rocks formed over—altered by water, how and when did the climate on Mars change, and how to best prepare for human exploration of Mars. Some of the rocks might even contain organic matter, or remains of former microbial cells. So, all in all, the samples brought back from Mars have the potential to revolutionize our understanding of whether life was ever present on Mars.

And, even if you don't find life—I get this question a lot, "So what if you don't find life?" By looking at samples from early Mars, we can always learn a lot more about organic molecules and processes that preceded life on Earth because of all this great age on these samples. And some of the findings that arise from the samples may even challenge our current interpretations of wife—what life is, or how to detect it. A lot of the findings, if not all of the findings, you'll also motivate future missions to Mars.

All this is great, but it's much greater than science. Since Perseverance landed, I've talked to hundreds of people, or to radio shows, and to schools, and I received dozens of e-mails from just random people from all over the world and from all walks of life. And what these e-mails and this personal communication has shown me is that Mars exploration inspires people to engage with science and technology because it resonates with people's innate curiosity about themselves, and our own place in the universe, and that curiosity in turn inspires us to do more. So I will be happy to answer any of the questions you may have.

[The prepared statement of Dr. Bosak follows:]

Statement of
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before the
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Committee on Science, Space and Technology
U. S. House of Representatives
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Hearing entitled:
What do Scientists Hope to Learn with NASA's Mars Perseverance Rover?

How, where and when life originated is one of humanity's great unsolved questions. Until now, we were only able to explore this question on our own planet, where the record of life before 3.5 billion years ago is absent. In contrast, Mars has preserved a rock record up to a billion years older than the oldest well-preserved rocks on Earth. Studying these rocks will enable us for the first time to probe the emergence of life on another planet. This is the goal of the Perseverance rover, which landed in Jezero crater on Mars. To achieve this, the mission aims to collect 30 samples of rocks and soils for future return to Earth as part of the international Mars Sample Return campaign. Scientists will then be able to analyze these samples in terrestrial laboratories. These will be the first set of samples from another planet that are relatable to specific locations and rocks or soils that formed in established sequences of geologic events. Just as the Apollo program did for the Moon, these samples will revolutionize our understanding of Mars science and stimulate enormous interest in science and technology for decades to come.

The scientific community identified many questions that can be addressed by studies of the returned samples. These include looking for past life, tracking changes of Mars's climate, atmosphere and habitability through time, establishing when rivers and lakes existed on the surface of Mars, determining how impacts and weathering affected the surface, and understanding the evolution of Mars's interior. Some of the returned samples will be collected in environments that were likely habitable during the time from which we have little record on Earth. Thus, for the first time ever, the scientific community will be able to look for the earliest stages of life by applying the criteria developed to investigate organic compounds and other potential signs of life in rocks from Earth. Analyses of returned samples can tell scientists what the earliest habitable environments looked like, whether early Mars received abundant building blocks for organic life from comets or asteroids, and whether some conditions at its surface enabled the synthesis of more complex organic compounds. Even more ambitiously, we can even ask whether any early life may have been transferred between Earth and Mars.

Following helicopter flights, the Perseverance rover will begin its traverse away from the landing site to explore an ancient lakebed inside the crater. During this traverse, the science team will acquire remote imaging, radar, and chemical data to characterize the geology of different regions at cm-to-km scales and establish the time sequence in which the rocks were deposited. Instruments on the rover's arm will also image the rocks at scales comparable to those shown by a hand lens, determine the composition of minerals, and look for potential signals of organic compounds in rocks. Samples judged to have the greatest potential for answering the key science questions will be collected, documented and cached for return to Earth. The selection of a returnable sample cache by the Perseverance rover team is critical for the success of the subsequent legs of the Mars Sample Return campaign. This requires the identification of samples that are most likely to preserve organic compounds under conditions that operated in habitable environments on early Mars.

On Earth, we can use a great diversity of instruments to determine the origin and ages of the samples, reconstruct past climate change, characterize organic matter and search for signatures of past life. Owing to the small size of collected samples, only small amounts of returned material will be available for analyses and most of these analyses will have to be performed at very small spatial scales, from nanometers to millimeters. These analyses can lead to a new understanding of the climate, the cycling of sediments, water, and inorganic and organic carbon on and within Mars. Any organic carbon present in the returned samples can also shed light on processes that control planetary habitability and lead to life. In the upcoming decades, the returned samples will likely stimulate new developments at the intersection of geology, geochemistry, geobiology, materials science, mass spectrometry, microscopy, spectroscopy, planetary science, chemistry, and astronomy.

I have always been interested in natural sciences, but growing up in Croatia as a first-generation college student, I never thought that I could one day be involved in the search for past life on Mars. Now, the weekly e-mails from school children and teachers, students, retired physicians, journalists and people with little-to-no background in science tell me that missions to Mars and sample return science resonate with people's innate curiosity. Scientists and non-scientists, in the US and abroad, want to know what samples from our closest planetary neighbor can tell us the earliest beginnings of life on Earth and humanity's place in the Universe.

Tanja Bosak was born in Croatia and graduated from the Zagreb University with a degree in Geophysics. After a summer of research at JPL, she moved to the California Institute of Technology in Pasadena, where she studied signatures of microbial processes in ancient sedimentary rocks and earned a Ph.D. in Geobiology. She spent two years at Harvard as a Microbial Initiative Postdoctoral Fellow, joined the Department of Earth, Atmospheric and Planetary Sciences at MIT in 2007 and is now a Professor of Geobiology and the group leader of the Program in Geology, Geochemistry and Geobiology.

Tanja's work integrates microbiology, sedimentology and stable isotope geochemistry into experimental geobiology to ask how microbial processes leave chemical, mineral and morphological signals in sedimentary rocks. Her lab uses this approach to explore modern biogeochemical and sedimentological processes, interpret the co-evolution of life and the environment during the first 80% of Earth history and look for signs of past life on Mars. For this work, and her work with graduate students and undergraduates, Bosak received the Subaru Outstanding Woman in Science award by the Geological Society of America (2007), the Macelwane Medal from the American Geophysical Union (2011), the Edgerton Award for young faculty at MIT (2012), the Undergraduate Research Opportunities for Undergraduates Mentor of the Year award by MIT (2012) and the Award for Outstanding Contributions and Dedication to Geobiology and Geomicrobiology from The Geobiology and Geomicrobiology Division of The Geological Society of America. Bosak is a fellow of the American Geophysical Union (2011), the American Academy of Microbiology (2021), and a subject editor for Geobiology, Frontiers of Microbiology and Geochemical Perspectives Letters.

Chairman BEYER. Thank you, Dr. Bosak, very much. Fascinating opening comments. I'll recognize myself now for 5 minutes for questions, and Dr. Bosak, I'm going to come right back to you. So you're our geowhatever.

Dr. BOSAK. Geowhatever.

Chairman BEYER. Geowhatever. Is the geology on Mars as varied as it is on Earth, in terms of the elements themselves, and the potassium, and carbon, and zinc, and—you know, basically are the building blocks there as they would be on Earth?

Dr. BOSAK. Mars is a rocky planet, and this is one of the reasons why we are so fascinated by it. It is so close to Earth. It is really the closest planet to Earth, and it does consist—because it's rocky, these rocks are the source of all the elements we need—well, a lot of the elements, such as iron and calcium, all of the stuff that goes into bones and so on. So Mars has all of that.

Now, the question of organics is a very interesting one, so carbon, nitrogen, oxygen, because rocky planets get these elements probably—and water as well—later in their history. Still really, really early in the big scheme of things, but later in the history, and we think a lot of that material came from asteroids and comets, so from elsewhere in the solar system. And so by looking at these old rocks from Mars, this is one of the—actually aspects of the mission, and the return sample that is most exciting to me—we could start asking how much delivery was taking place. What is this background delivery of these compounds that are needed for life to rocky planets?

Chairman BEYER. Thank you very much. Dr. Meyer, you've been a specialist in astrobiology. Dr. Bosak earlier talked about, you know, life evolving, you know, trying to understand. Was the organic soup ever there, the lightning? You know, our limited understanding of how life evolved on Earth, could those conditions have been on Mars also?

Dr. MEYER. Well—so that's actually one of the big questions. We think so, and that's half the reason why we're looking, but, in all honesty, there's three major theories about how life got started on this planet, and we don't have very good evidence to point one way or the other. And, as Tanja talked about, rocks on Mars—over 50 percent of the rocks on the surface are ancient, and here on Earth they're few and far between, and they've been worked over. So evidence of exactly what was going on in the first billion years of terrestrial planet history, we don't have a very good record on Earth, and we think the record is on Mars. So whether or not we had the organic soup, and lightning that caused life, or whether or not it was a hydrothermal vent, these are things that going to Mars can help us sort out.

Chairman BEYER. Thank you very much. And, Dr. Ehlmann, as our planetary scientist, we saw Elon Musk last week, the week before, talk about terraforming Mars. Is there enough water there to justify that? Can you see transforming the Mars environment sufficient for human life?

Dr. EHLMANN. Well, I will say that the premise is correct in that Mars is the closest potentially habitable world, right? It is really the only one that has an atmosphere today, as well as abundant water resources. We know right now, you know, the water is in solid ice, so the question is can—does the ice melt now naturally, right? That's a question Perseverance won't answer. Is there modern life that could be associated with this ice? I think I'd actually like to answer that before we send humans.

But regardless, terraforming Mars would be hard, so—I'm a planetary scientist, but I'm also a geologist by training, and I know that to make a planetary atmosphere thick for humans to breathe, you have to figure out some way to produce oxygen, you have to figure out some way to thicken the atmosphere so that it's warm enough, and on Mars lots of the water and the carbon dioxide are actually trapped in rocks, so hard to release. I would love to send humans to Mars to explore. Changing the whole planetary climate, maybe not so much.

Chairman BEYER. Yeah. I love the optimism, in any case. Is there enough gravity there to hold an atmosphere?

Dr. EHLMANN. There is, and Mars has an atmosphere today. It's a little less than 1 percent of the thickness of Earth's atmosphere. It's 96 percent carbon dioxide, but very, very, very thin.

Chairman BEYER. That's great. Thank you. Dr. Beegle, very quickly, do we have enough talent in the pipeline? You know, we worry so much about STEM education——

Dr. BEEGLE. We do. We have some very—I look at the postdocs and graduate students that are working on Perseverance, and had worked on the development of Perseverance, and there's some outstanding talent coming up, and even more on the way as we continue to push people in a—well, not push people, but inspire people to go into science and technology. We have a great pool to draw from.

Chairman BEYER. That's very encouraging to hear. Let me now recognize my friend Dr. Babin for his 5 minutes of questions.

Mr. BABIN. Absolutely fascinating. I just want to thank all four of you for being here, giving us your testimony, and, Mr. Chairman, thank you for having this. I guess my first question would be for Dr. Bosak. I proudly represent the Johnson Space Center (JSC) here in Houston, where many brilliant, hardworking government employees and contractors also work here. JSC is at the center—or presently charged with curation of extraterrestrial samples, and is home to the Astral Materials Acquisition and Curation Office. JSC has experience curating samples from the Apollo Moon landings, meteorites, cosmic dust, and the Genesis, Stardust, and Hayabusa missions, and will process samples from the Osiris Rex mission. The Mars Perseverance mission is gathering and storing samples for an eventual Mars sample return mission—fascinating—which is still in the planning phase.

From your perspective as the co-lead on returned sample science for the Perseverance rover mission, does NASA plan to store and curate Mars sample returns at Johnson? And what impediments are there to using JSC's Astral Materials Acquisition and Curation Office, and the unique capabilities that JSC possesses? Because I would like to do everything that I possibly can to eliminate whatever impediments those might be.

Dr. BOSAK. Unfortunately, I'm not—well, not unfortunately. We are really responsible—the team of Mars 2020 mission, the Perseverance rover mission, is responsible to—for recognizing, identifying, and collecting the best samples, and the plans for curation, storage, later allocation, are all under development by the Mars Sample Return Program. So I think the plans are being developed not by necessarily the members—the teams members of Mars 2020. I think Michael can speak more to that.

Mr. BABIN. OK. Dr. Meyer, can you speak to that?

Dr. MEYER. Yeah. I mean, Johnson is long recognized for their expertise in astral materials, and I think they do a fantastic job, and we are targeting Johnson to be the implementation lead for the samples that come back from Mars. Where the facility is actually located hasn't been determined yet, and part of that is just whatever other factors are coming into play. And, as an example, we're right now on an international group, competitively selected, trying to work out what the requirements are for the facility because, as you know, the Mars samples are unique, and they have some challenges of not only keeping them pristine and doing the best science that you can on them, but also keeping them contained while you're trying to do the science, at least initially.

And—so we're going to—you know, we would like to open that up and have—when we figure out, really, what the requirements are, and what our capabilities are, in terms of—facility that we can do, Johnson will lead that effort, in terms of determining where the actual facility is.

Mr. BABIN. OK. Thank you. And I guess your testimony also highlights how Perseverance is paving the way for future crewed missions to Mars by demonstrating oxygen production with a MOXIE instrument, and the use of terrain relative navigation that you had mentioned. Can you speak to how terrain relative navigation will also assist future Artemis missions to the Moon, and how it could be incorporated into human landings?

Dr. MEYER. Yeah. Well, certainly the issue with—particularly with Mars, and in the—and the Moon is that there's a time delay between when something happens and when people on Earth actually get to see it. So when you're trying to pick precise landing, you know, you want to land next to the equipment you left, you know, that you put there for your humans to go to, or resources that are available, you need precision landing. And terrain relative navigation has shown us that we can do it autonomously. And so for that we know that we can put things on the surface of another planetary body, and put humans right next to them so they can use them.

Mr. BABIN. Thank you very much. And now, for Dr. Beegle, is the Perseverance rover looking for signs of life or signs of ancient life? If NASA is only searching for signs of ancient life, is this because the instruments are too complex, or perhaps too costly, to search for extant life, or because NASA doesn't believe that Mars is capable of harboring life more. Understanding that you may be a little biased as a Mars researcher, how should this information play into considerations of whether to continue exploring Mars, or to focus more on Venus, Europa, Ganymede, Titan, or other celestial bodies?

Dr. BEEGLE. So we're looking for signs of ancient life because we simply don't believe that Mars is habitable, at least to the upper few centimeters, today. But as Dr. Ehlmann has pointed out, that

Mars is the most Earth-like planet, and if life started there, we would assume that life would—if we find that—signs of ancient life, we could tie it back to what started life on the Earth, and Europa and Ganymede may have had different origins of life, if it started there at all. So while we could find it if it was there, I—we don't expect any extant life to be present.

Mr. BABIN. OK.

Dr. EHLMANN. If I——

Mr. BABIN. Did somebody want to say something?

Dr. EHLMANN. If I could just briefly add, I think—wanted to emphasize—Luther noted—Dr. Beegle noted that it's the upper centimeters that we don't think are habitable, but once you get down a meter, or maybe a few, it gets a lot better. You're out of the radiation, you might be near some ice or water. So that's the place to look on Mars.

Mr. BABIN. Well, you know what, I didn't get a chance to ask you a question, Dr. Ehlmann, but thank you very much for that answer. And I could go on for the next 1 hour at least, but I'll have to yield back, Mr. Chairman. Thank you.

Chairman BEYER. And, Dr. Babin, I think we're going to do at least a second round, because our curiosity is large. And——

Mr. BABIN. Absolutely.

Chairman BEYER. And with that, I'd love to introduce perhaps the greatest enthusiast for Mars exploration in the U.S. Congress, the author of the Mars 2033 bumper sticker that many of us have, Congressman Perlmutter.

Mr. PERLMUTTER. And I'm sorry I don't have that today, because I'm in California, but I've got to tell a story. So, Dr. Bosak, your question—or your comment about the enthusiasm of people, you know, reaching out to you—so I chair a different—Committee on Financial Services, the Banking Subcommittee, and I was getting interviewed by the *Wall Street Journal* just as Perseverance was landing a month or two ago, whenever it was, and I couldn't talk about banking. All I could talk about with this guy from the *Wall Street Journal* was the Perseverance landing, and it's because I was so excited about it. And I am excited about the efforts and the successes that you've had so far.

And Dr. Babin, you know, I mean—a lot of times you can't have success without, you know, a few trials and errors, and we've had those too. But this one seems to be—you know, each time you try something—Ingenuity it took you, you know, reprogramming it a little bit before it could take off. You know, the cameras, Dr. Beegle, seem to be working fantastic. We haven't quite tried the drilling yet, I don't think, but, you know, you're taking these one step at a time. So I want to talk about MOXIE, and I want to talk about Ingenuity, if I could.

And so explain to me the process—what's going on with MOXIE as we're figuring out how to create oxygen on this planet, which will benefit us, you know, in many different ways? And I just open all of these questions to all the panelists, so jump in as you choose. Dr. Beegle?

Dr. BEEGLE. So I can explain what's going on with MOXIE. And MOXIE had—did a run the other night where they take CO_2 out of the atmosphere, and they turn that CO_2 into breathable oxygen, or oxygen that could be used for rocket fuel. They run overnight. It's a wonderful instrument, and they created enough that you could breathe on Mars for 10 minutes, which doesn't sound like a lot, but really is. It's the start of that whole process, and it's a fascinating instrument.

Mr. PERLMUTTER. Anybody else want to talk about MOXIE? And then we'll get to Ingenuity. OK.

Dr. MEYER [continuing]. It's OK, what I would like to mention is that the way it does it is it splits the molecule, so it strips the two oxygens off of the carbon, and that's how it's generating oxygen. So it's kind of a neat process. It takes a catalytic converter, but it's a test. And the volume depends on how big of a thing you want to use.

Mr. PERLMUTTER. Great, the old catalytic converter. That's amazing. So, Dr. Meyer, do you see this as sort of a precursor of some kind of bigger system that would then, you know, enable our—if—so I am a big proponent of human space exploration, and hope to see our astronauts on Mars by 2033, and I wish I had my bumper sticker for you, but I don't. Do you see this as something that will—we could put together to really provide oxygen for our astronauts, or for fuel? I mean, in it—so, you know, a massive kind of approach to this?

Dr. MEYER. So how I see the real advantage is is that you can put a system for—like MOXIE onto the surface of Mars, and have it operating for years, and then send humans, or then send your return spacecraft, and you can make use of that oxygen that has been generated.

You know, one of the things to keep in mind is that rocket fuel is an oxidant and a reductant, so, like—something like methane or ethanol, and then the oxygen. Well, the oxygen is actually the heavier part, so this goes a long way in making—getting to the surface of Mars with something you can return—if you make most of the mass of your fuel on the planet itself, it's a huge advantage.

Mr. PERLMUTTER. Great. To the geologists, how are you going to use Ingenuity to help you explore a little bit of the geology up there?

Dr. EHLMANN. I guess I'll start, and then hand it over to Professor Bosak. So, you know, Ingenuity is a technology demonstration. You know, it wasn't even originally part of the mission, but I think that is part of the reason that we explore, and that is part of the reason the U.S. Space Program is so outstanding is that we dare to do audacious things, like fly a helicopter on another planet. Like, wow. And you know what? We figured out how to do it. It worked.

And so Ingenuity is going to, you know, on its final flight, scout out some of the terrain around us, we hope getting a closer view than what we have from orbit, but what I think's super important is how it paves the way for future exploration technology. There are already folks at JPL who are talking about, "Well, you know, what if, instead of carrying a tiny little 500 gram cell phone camera, could we put 5 kilograms of science payload on there so we could fly down the canyons of Mars from spot to spot, taking images, making chemical measurements?" So I think what's important about Ingenuity is it's paving the path for future exploration.

Mr. PERLMUTTER. Thank you very much. My time is expired. Mr. Chairman, I love this stuff. I yield back.

Chairman BEYER. That is obvious, Congressman Perlmutter, and we're all so fortunate. Let me now recognize the Ranking Member of the Full Committee, the past Chairman of the Science Committee, Congressman Frank Lucas.

Mr. LUCAS. Thank you, Mr. Chairman, and I address my questions to the panel in general. This Committee's always promoted a balanced portfolio at NASA, and we worked very hard to—by the informed nature of the National Academies Decadal Studies. Our Committee's always been very supportive of planetary science missions throughout the solar system. Given the number of Mars missions during the last decade, how would you recommend we balance the planetary science portfolio in future years? Anyone that's willing to touch the wire, I'm happy to listen.

Dr. EHLMANN. Well, sure, I'll touch the hot wire. So what's most important is that, you know, scientists, we need to get together and prioritize our science, and then communicate those messages to Congress, to the President, and so we're in the process of doing that right now through the National Academies Planetary Decadal Survey process. So over the last, you know, year, year and a half, we've been trying to hash out that question, arguing amongst ourselves, "Well, what is the right balance between outer solar system, inner solar system, small missions, big missions?"

You know, I think the answer is we need a Mars exploration program because Mars is unique. Mars is special. Mars sample return is an enormous investment, but it pays it back. It pays it back in terms of proving how we can come, and then go, and then bring back. We would want to do that before humans, and the science return, as Professor Bosak said, will be amazing. So we need to have that balance, and we—I can say the Planetary Decadal Survey looks forward to communicating to Congress its relative prioritization.

Mr. LUCAS. Absolutely. Perseverance has——

Dr. BEEGLE. And I'll also——

Mr. LUCAS [continuing]. Already demonstrated—please.

Dr. BEEGLE. Sorry. I'll also add that we do the other missions as well, so there is a balance for working on the Europa—the orbiter mission right—on Europa flyby mission right now, Europa Clipper, and there is the—I think there is the balance—I think most people in the community think there is a decent balance.

Dr. MEYER. And I would just like to add one thought, if that's OK. It's balancing the science of planetary sciences, not necessarily equal number of targets, in terms of missions. And in some ways Mars has an advantage because of the amount of information that we can learn from exploring Mars, and the short—let's say the not so long time to get there and get the information back. So it has a little bit of an advantage, so I don't feel so bad that we've had so many missions to Mars, because they have really returned—fantastic amount of data. And I don't envy Bethany's job on the decadal to—helping sort out what those priorities are.

Mr. LUCAS. Absolutely. Perseverance has already demonstrated multiple technologies that'll assist in the future human exploration of the Moon and Mars. And to help Mr. Perlmutter achieve all those goals, what are some of the examples of technology demonstrations on future planetary missions which will further assist human exploration throughout the entire solar system? Again, I'm trying to help Mr. Perlmutter.

Dr. MEYER. I'll take a quick crack at that, and hopefully my other—fellow witnesses will chime in. But there are things that will really help human exploration that we actually haven't demonstrated yet, and that is, for instance, rendezvousing in space with your spacecraft, testing out operations—so one of the challenges are—I used to do field work, and there's a world of difference between doing something where you're 3 days away from help, like a hospital or food sources, compared to multiple years. And so I think one of the key parts of Gateway, and the Artemis Program, is, in fact, testing out your operations and your housing for the astronauts to be reliable on the long term.

Dr. BEEGLE. I would also add that there's an aspect of autonomy that we don't talk enough about. There's a couple versions of autonomy. One is the rover drives itself, but there's also the idea that the rover can figure out how it's working, and how it's functioning, and what its basic mechanical state is. As we develop more and more autonomy to—for the rover to figure out what's going on, that helps in human spacecraft because you will have the human rovers, and equipment, and things like that, really be able to understand how well it's functioning, whether or not it's about to break down, which is something that would be very valuable for human missions.

Mr. LUCAS. My time's expired. I wish to thank the panel for those insights, and yield back to the Chairman.

Chairman BEYER. Thank you, Congressman Lucas. I now recognize the Congressman from greater New Jersey, leaders on education and labor, Congressman Norcross.

Mr. NORCROSS. Thank you, Chairman, appreciate it. And the people who are on this call, you can just see the smiles because it's things that we believe passionately about. As a young man, you know, the Mercury, Gemini, I was one of those kids that got NASA tech briefs when they used to be put out on paper. I had no idea what I was looking at, but it's that sort of driving force that keeps me and so many involved because it's about what we're learning.

I want to talk about private investment. If you Google private space, you'll get 25 different companies, so I sort of split those into two categories, those who are facilitating different components, whether it's the rocket or the instruments. The other side of that is private investment into space. What do you think drives the private investment for the future, and I'm assuming this is way in the future, to either Mars, to an asteroid, or others. What would drive them that there is a payback, and when do you think that would happen? I know it's a wide open question, but at some point you do all the work, and somebody comes in and takes the profit out of it, but where do think that—and where do you think it would be? And that's for all three. Love to hear that.

Dr. EHLMANN. Guess I'll start us off. So there's, you know, private industry has been—has always played a huge part. You know, so many of the procurements for our rovers and instruments are from private companies, so big role. I think what you're poking at, though, is that that role seems to be changing a little bit, and I think it's driven by the increasing access to space, driven by lower launch costs, and a number of companies are competing in that arena, just lowering the cost of access.

The other thing that's happening is with small sats, and with commercial technology in orbit, there are many more entrants into this field, many more private companies, small private companies, building components, so I think the motivation is largely profit, that we see a market in space. And I think one of us—the challenges for us as planetary scientists is to think about how to extend that market to enable more exploration and more activity. It's happening at the Moon, with the Commercial Lunar Space Flight Program. I want to highlight the lunar CLPS (Commercial Lunar Payload Services) program, which I think can be extended to Mars if we, like, for example, regularize the delivery, or set up, you know, comm infrastructure contracts to provide communications from rovers and landers back, these are things industry could do, so we have to think about what's the right role—what's the right contracting vehicle to have, you know, shared risk, for example, in some of the development, and how do we incentivize that? Some people want to go anyway, right, just to go. Like, Elon Musk is an example, right? Others, they see the market, and so we need to think about how to incentivize that to enable more exploration.

Mr. NORCROSS. If I could, just to sort of narrow the focus, I—plenty of investment to getting things out there, the Rocket Lab, SpaceX, the list goes on. Moving beyond what we already know as commercial space around our planet, the Moon, Mars, or others, what's going to drive them into that next spot? You know, how long did it take to really get private investment around our own planet from when we started this game, right? 40 years. Where do we think this is going, and what would drive them to go to, like, Moon, or back to Mars? What do you see as a reason for them to go there?

Dr. BEEGLE. I will——

Dr. MEYER. I'll——

Dr. BEEGLE [continuing]. Say that there's—well, there's—I'll just say real quick that there is a cadre of companies that are looking into asteroid mining, and that is something that is—it seems to be picking up speed, so that would be the first commercial aspect of return on investment that potentially would be made 1 day. But, beyond that, that's—I will defer to Mike Meyer—Dr. Meyer.

Dr. MEYER. Well, I am certainly not the expert, and this is highly speculative, but I remember——

Mr. NORCROSS. Absolutely.

Dr. MEYER [continuing]. Talk about 15 years ago at a Committee on Space Research assembly, and it's actually—the person said, "We will be at Mars with humans sustainably when it becomes"—"when you're able to do it for tourism." And when I heard that I thought the person was nuts. But then the more I thought about it, and the more I had to answer my cell phone, the more I thought, "What a great pleasure it'd be where you get someplace where you're so far away that you can't have regular conversations with everybody else who wants to talk to you, but you could actually take a vacation, and you would be someplace entirely exotic for an extended period of time." And it makes more sense to me now.

Mr. NORCROSS. Can I suggest a CODEL (congressional delegation)? Maybe to Mars, Mr. Chairman? Thank you, I yield back.

Chairman BEYER. We'll request—we'll ask the Full Chairman and the Ranking Member for permission to schedule that CODEL. Thank you Mr. Norcross. I now recognize a Congressman known for many reasons, but best known as the Congressman from Cape Canaveral, Mr. Posey.

Mr. POSEY. Thank you, Chairman Beyer, and Vice Chairman Babin, for holding this very, very interesting hearing.

Dr. Meyer, you mentioned that just getting a spacecraft to launch during the pandemic was no easy feat, and I assume especially considering the 2-year window. Can you describe some of the challenges that COVID–19 posed to launching on time, and how NASA and ULA (United Launch Alliance) were able to work together to overcome those challenges?

Dr. MEYER. Yeah. I mean, this is something that, with only being able to talk for 5 minutes in the beginning, is something that I wasn't able to delve into, so thank you very much for the question. I think it is a tremendous heroic effort. And, as you mentioned, just getting a spacecraft to a launch pad on time to meet the planetary window, that's a huge challenge. And, as we know, in the past, we don't always make it, and this time, having COVID show up, you know, basically in the middle of what's called ATLO, Assembly, Testing, and Launch Operations, it was tremendous.

And—so one of the things that really struck me was the whole operation team down in Florida had to basically form their own COVID bubble. So they had to be with each other all the time, which is maybe not necessarily a bad thing, but, you know, they had to self-isolate in preparation to going to Florida, and then while they're at Florida, and then how did you do summer rotation? It was an extreme challenge because that was the only way that you could actually get together and work on the equipment that you have to send to another planet. Otherwise—you can't do it all by Zoom.

Mr. POSEY. Well, thanks, that's a great answer. In your conclusion you state NASA's Mars Declaration program continues to lead the world in learning about Mars and developing technology that allows us to delve even deeper into [inaudible]. I was just wondering, with this being the ninth mission to have a U.S. spacecraft successfully land on Mars, what are some of the secrets that might be——

Dr. MEYER. Well, this is a public meeting. Do you want me to reveal those secrets?

Mr. POSEY. Well——

Dr. MEYER. Yeah.

Mr. POSEY. What do some people hope we will find? On the best view of things what could we discover?

Dr. MEYER. You mean what we may find on Mars? Or are you talking about what the challenge—the—sort of the—how do we—how have we been successful? I'm——

Mr. POSEY. No, just——

Dr. MEYER. I'm kind of——

Mr. POSEY. Yeah, I think you mentioned that as we delve deeper into the secrets of the red planet with each mission, what might we be looking forward to finding out about Mars?

Dr. MEYER. So—yeah. So—OK. Well, as been mentioned, Mars is very similar to Earth, and—some aspects to it that I think are absolutely fascinating. One of them is it's gone through huge transformations in its climate, and this happens on multiple time scales. And—but the record is—what the planet actually did is there. And so, in some ways, we can look at those rocks and determine, well, what happens when you increase the atmospheric pressure by twice as much, or 10 times as much, or, you know, even as much as Earth? You can look at how very—how the tilt of the planet has varied the climate. It really helps you to test your climate models on another planet where they—the planet itself has done the testing for you. It's done the experiments. And so then you get a much better idea of how a planet behaves with its atmosphere when conditions change.

And it's kind of simple in terms of—for instance, on Earth, while we're increasing the CO_2 in our atmosphere, and we have models that kind of tell us what we think is going to happen, Mars has some great examples of extreme variability that will tell us—and give us a much better idea of how that's gone back and forth. And, real quick, I think this has already been mentioned, but certainly should never be forgotten, if life got started on Mars, there are still places where we think that life could be there today, and that's going to be a real challenge. And let's say the last—that we can think of as scientists is in the deep subsurface in—where we think that there are potential aquifers. So that's one of those—almost a horizon goal, in terms of looking for life on Mars.

Mr. POSEY. Well, that's super interesting, and I thank you for explaining that to us. And I see my time has expired, so I yield back, Mr. Chairman.

Chairman BEYER. Thank you, Mr. Posey, very much. Now recognize the gentleman from Florida, Governor Crist.

Mr. CRIST. Hello, Mr. Chairman. How are you today?

Chairman BEYER. Excellent.

Mr. CRIST. Great, great. Is it my turn? I'm sorry, I couldn't hear you for a minute.

Chairman BEYER. Yes, it is your turn.

Mr. CRIST. Thank you. Thank you so much, and I want to thank the witnesses for being with us today. Dr. Bosak, can you discuss what you are trying to find on Mars that would indicate microbial life, and how you will know definitively if life does exist on Mars, please?

Dr. BOSAK. Yes. So we are looking for past life. We are looking for life as it may have looked like 3.5 billion years ago, or even earlier, so we are not looking for current life. And basically——

Mr. CRIST. You're looking for dead life, is that what you're saying?

Dr. BOSAK. Dead life, exactly. So what we are looking for are fossils——

Mr. CRIST. OK.

Dr. BOSAK [continuing]. Fingerprints of some fossil life. And I can actually show you some examples of rocks that would tell me, just based on their shapes, that there must have been some life there. And that's probably the holy grail of we—what we can hope for by this mission, just to see something in the field. But, because we are looking for life that—really, from everything we know about life—microbial, we will have to bring samples back, and we will have to analyze these samples with—it won't be one person who looks at one sample with one instrument and says, "I think I see an outline of a cell, some former microbial cell", and—so we are talking something that is microscopic. But there will be another team that has to look at that outline and say, "Yes, I see organic carbon in there." And then there will be another team looking at the same outline and saying "Yes, we see some concentration of elements that usually go with carbon in living organisms." And then someone else will have to measure the shapes and sizes of all these features, and say, "Yeah, they really are consistent, and we cannot think of any processes that can create that." It can't be just oil bubbles, or something—you know, some asteroid delivered some material. So there will be a lot of different tests that'll have to go—because it's an extraordinary claim. And before we make those kinds of announcements, we will have to really make—as certain, based on the knowledge of the time, that this could be life. We'll—everything else.

Mr. CRIST. Wonderful. Thank you. Dr. Ehlmann, you note in your testimony that the rock record on Mars extends much further back in time than what is preserved here on Earth. Based on what we know of Mars right now, do you think it's possible that we could find signs of life on Mars that are older than the first signs of life on Earth?

Dr. EHLMANN. That's actually a great question. The oldest life that people sort of agree upon on Earth in the fossil record is about 3.5 billion years old. There are hints of earlier life, you know, maybe as far as 3.8, but the problem with our Earth is that, one, we have tectonic plates that deform the rocks, that heat them, that mess up the textures. And also, frankly, new Earth life eats organics from old life, so our life itself is destroying the record of past life on Earth. So, yes, I do think it is possible—it looks like all the conditions existed on Mars 3.5 billion years ago to create habitable environments. The record is much more pristine, though, because it's sort of captured frozen in time over 50 percent of the surface. So we have lakes, rivers, aquifers, like underground in Florida, and hydrothermal systems, all of which are different types of environments to look for life.

Mr. CRIST. Wonderful. Dr. Meyer, when talking about the possibility of life on other planets we hear a lot about liquid water, and looking for signs that conditions are right for water to exist. What are some other known requirements for life as we know it to exist on other planets?

Dr. MEYER. Yeah, it is broader than water, because, you know, with water at least we find that consistent, and we don't have to argue about it with life here on Earth, and what we think life is—you know, what the potential for life is in our solar system. But yeah, there are certain major things that should also be there. One of them is, of course, the right elements, carbon, hydrogen, nitrogen, phosphorous, and sulfur. Those are the things that we're all made out of. That's what everything that's alive on Earth is made out of, so you would hope you have those. You probably want certain compounds. You may want some trace elements, because they're important for enzymes to work, and that sort of thing.

The other is, in fact, energy, and this may be a more challenging one to look for for extraterrestrial life because, if you don't have enough you can't do anything, if you have too much, the energy is too much, and it destroys what complexity is liable to evolve. So those other things are sort of other things you would look for. And, in fact, one of the great things that Curiosity did within the first year of its mission is, in fact, it found everything that we can think of that are required for life, and that's why we can now say, yes, barely, at least early Mars could have supported life, if it ever got started there, because it has all the right ingredients.

Mr. CRIST. Great. Thank you, Doctor, and, Mr. Chairman, I'll yield back. My time has expired. Thank you.

Chairman BEYER. Thank you, Governor, very much. And we can move to a second round for anyone who's brave enough to hang in there. But I completely understand, as busy as our schedules are right now, if Members have to go off to other things. So let me begin, and, by the way, thank you, Dr. Babin, for co-chairing this with me.

First I want to apologize to our panelists for having Andy Weir appear before the Space Subcommittee before you, you know, and we actually packed the room with press. But, anyway, that's just—on sample return, and maybe this is a question for Dr. Beegle, are we dependent on the human space flight to Mars to retrieve it, or can it be retrieved in the meantime?

Dr. BEEGLE. That's a great question, and the answer is that we can retrieve it in the meantime. There is a series of missions that are proposed that Dr. Meyer could talk more about that will go pick up the samples that we're collecting, and eventually bring them back in the 2030 timeframe. And all that can be done robotically.

Chairman BEYER. So 2030, so a couple years ahead of the Perlmutter schedule for human space flight to Mars?

Dr. BEEGLE. Yes.

Chairman BEYER. OK, excellent. Great. Let me ask a deep, existential question for you guys. Of the four of you—and I rarely ask for—the whole panel a question, but I'd love to know where each of you are on your belief that there is other life in the universe, that life seems to be so unique, and consciousness itself so unique. Dr. Bosak, can I start with you?

Dr. BOSAK. Certainly. I will tell you this, one of my favorite, if not my favorite science fiction book is "His Master's Voice" by Stanislaw Lem. He was brilliant. And it is not so much about whether there's life, but about the people's need to look for signs of life, and interpret signals, and keep interpreting signals. The whole book is about this whole field of science, and people being fascinated by a tiny signal they captured from some star, and arguing about whether it's a signal at all. So I think part of the excitement—and I wouldn't—I think this—consciousness that makes us unique. I think the search makes us unique. It——

Chairman BEYER. Could——

Dr. BOSAK [continuing]. Really makes us something bigger than just, you know, microbes converting energy to live. But then again, if I start thinking about life, I think mostly—I'm a microbiologist, really, so I think of life mostly as microbes, and that probably doesn't have too much consciousness, yet it can be really easily spread. And, in fact, even the ancient Greeks talked about seeds that could travel from stars and planets to other planets. And this is the really cool thing about this mission, and the sample return, because we can actually test some of that. There is a strong idea that maybe life even started on Mars, and then it was transferred to Earth early on. And we can start playing with these ideas. We can look at these samples and see how similar—if anything we find, how similar it is——

Chairman BEYER. Well, thank you——

Dr. BOSAK [continuing]. Like——

Chairman BEYER [continuing]. For the book recommendation——

Dr. BOSAK. It's great.

Chairman BEYER [continuing]. Just—begin with. Dr. Ehlmann, is there other life in the universe? I mean——

Dr. EHLMANN. I——

Chairman BEYER [continuing]. Your leap. I know—you know, just—what do you think?

Dr. EHLMANN. Yeah. I—this is one of the reasons we explore. I think there is, and I think many people think it would be strange that in the vastness of the universe, with—and billions of stars, each of which have many planets, that we are the only ones. But if—I agree with Professor Bosak that it's the search that matters. It's the search that's inspiring. And, you know, just even thinking about our own solar system, the question was asked earlier about the portfolio of exploration and balance, we now have the technical capability to look for life on Mars, on Europa, on Enceladus, on Venus. We should do it, because this is an inspiring journey that really will inspire the whole country to do hard things. And let's start the questions with the life questions in our own solar system, where we can access the planets, while we keep using telescopes to look beyond.

Chairman BEYER. Thank you very much. Dr. Meyer, I guess, since you call yourself an astrobiologist, that that may be implicit in your title, but what do you think?

Dr. MEYER. Yeah. I—that's a big yes. I mean, as Bethany says, there's, like, 100 billion stars in the galaxy, and there's 100 billion galaxies. It would be absolutely, spectacularly amazing and hard to believe if there wasn't life out in the universe. The real question is how common is it? You know, because if it's on the other side of the universe, how likely it is that you'd ever find it, or notice it. And so the real question is commonality.

And, as Bethany says, you know, in our own solar system, we see multiple places that are—have real potential, and we are the first generation of people on this planet that can actually do experiments, can actually go and look, and answer the question how common life is in the universe.

Chairman BEYER. That's very cool. I'm going to use my extraordinary power as Chair and let myself go over because I want to hear Dr. Beegle's ideas also.

Dr. BEEGLE. So I agree with Dr. Meyer, Dr. Ehlmann, and Dr. Bosak that life is—the odds of life not existing elsewhere in the universe are very slim, that—the questions we ask ourselves a lot is the—how—is there more than just single-celled organisms? It took a long time on Earth before life revolved from the single-celled organism to multi-celled organisms, and that's the question we continue to ask and ponder, which is a much more difficult question, because it involves understanding the evolution of life on different planets, and you have no idea what the conditions are like, and that's the question that we really are trying to sink our teeth into.

Chairman BEYER. Thank you very much for—and I ask this because—well my favorite recent book is Max Tegmark's "The Mathematical Universe", who finishes with a strong argument against there being other life. And he says in any room full of scientists he'll ask who believes in life elsewhere in the universe, and every hand would go up, and then he argues against. But I'm not going to try to recreate the argument, but it is interesting. However, I will like to recreate the Congressman from Denver, Mr. Perlmutter, for his questions.

Mr. PERLMUTTER. Thanks, Mr. Chair. And he sent me that book, and I'm trying to wade through it. It's a pretty heavy math book, but—he's trying to educate us as part of this Subcommittee.

So, Dr. Meyer, let me start with you. When I was talking to Dr. Ehlmann about Ingenuity, she said it was an audacious addition to the project. So how—and for the others, how do you get your experiments—you know, once you've decided we're going to send another rover up to Mars, I mean, how does Dr. Bosak get her experiment on your—on the trip? So let me start with you, and then I'd like to hear from their side how they manage to get their experiments as part of the whole process.

Dr. MEYER. Yeah, it—well, I'll put it this way. It's quite a gauntlet, in terms of what's needed, but as we've done for Curiosity, and we also did for Perseverance, we put a call out that says we're going to send a mission to Mars, this is what the goal is, send us your proposal for an instrument, and we'll see how it all fits together. And so it very much is open competition for people to propose whatever they think is applicable to the goal, right? And—very rigorous competition. It is—it's actually very hard to go through the whole process, and then you have to choose—you have to narrow it down to those things that will fit on the mission from all the excellent proposals that you receive. And then there's a little bit of a give and take where you don't want to send two of the same instrument, you want to make sure they complement each other. You want to make sure one instrument doesn't use all the resources on the mission. So there's a little bit of making sure they fit well together.

But the real process is individuals, obviously experienced in having a whole team behind them, proposing what they think would be the best instrument, and then the whole review process to select that, and that's been extremely successful so far.

Mr. PERLMUTTER. Great. Dr. Bosak, how did you get involved with this project?

Dr. BOSAK. I answered one of these proposal calls. When all the instruments already had been selected, and really advanced in the works to get on the rover, there was a proposal call by the Mars program to select participating sample scientists, and they were looking for people who actually work on samples in laboratories, because they wanted to ensure that people who—that people think about how to collect a sample, how to orient a sample. And there is a diverse team of us who were selected, so we wrote proposals about what we could do with these samples, and how we would take notes to document and tell people why we selected certain samples.

Mr. PERLMUTTER. Great. Dr. Beegle, how did SHERLOC become part of this?

Dr. BEEGLE. It's a pretty simple process. Back in the mid 1990's we started thinking about ideas on how to send something to Mars to look for life. You write a proposal, you write more proposal, you write another proposal. You have to go in and do the scientific rationale behind what measurement you're going to do at the same time you're doing the engineering to show that you can actually do it. There's a lot of instruments that fail on one of those two things because it's a very complex environment, scientifically, to make a measurement, and it's a very complex environment from a—temperature, pressure, radiation, and everything else, that—you have to show—vibrations—you have to get your technology to work.

You write a bunch of proposals, you write a bunch of papers, you get scientific buy-in, and then in 2012 we knew that there was going to be an announcement of opportunity. We spent a year writing the proposal, we submitted the proposal, proposal got accepted. There were 58 different concepts that went into that call, and we were one of seven that got selected. And then the fun really begins, where you actually have to build your instrument that's the size of a room down to a size of a shoebox, and show that it works. It's a fun process.

Mr. PERLMUTTER. Well, it sounds—starting in the 1990's, it sounds like you were able to perfect it over a period of time, so thank you. Dr. Ehlmann, what about you?

Dr. EHLMANN. I guess I'll talk bout something that people don't always talk about, which is kind of the failure aspect of instrument proposals—or not failures, but lack of selection. So, you know, I'm privileged to be part of two extraordinary instruments, one led by Dr. Beegle, I'm part of his team, and then Dr. Jim Bell at Arizona State, part of his team. I also led a team that proposed an instrument, one of the 50 or so to the rover. We ranked Category One, which is as high as you can possibly rank, but in the end we weren't selected. Reasons of balance, reasons of—but this is where, as scientists, we compete, and then we collaborate, and we do both simultaneously, and that's what brings the best ideas to the forefront.

I've gone through this process again, a different mission, different competition, different call, one of NASA's small sat competitions, and I'm the Principal Investigator of Lunar Trailblazer, a small satellite going to the Moon that will map its water. So it's a process. Sometimes you win, sometimes you don't, but you keep going forward to do the best science, and bring the best instruments and missions to light.

Mr. PERLMUTTER. Thank you very much. I yield back, Mr. Chair.

Chairman BEYER. Congressman Perlmutter, thank you so much. It's—I love serving on this Committee with you. And this brings our hearing to a close, but I do have one final question, is—after Mars, Europa? What do you think?

Dr. EHLMANN. Europa for sure, Europa Clipper mission.

Chairman BEYER. OK.

Dr. EHLMANN. Enceladus would be great too. Venus, all sorts of good things.

Chairman BEYER. But Europa we could actually land on, right? And water, and——

Dr. BEEGLE. One of the missions—I think the next mission to actually look for extant life, what—as Bethany—Dr. Ehlmann pointed out earlier was—is drilling, is getting underneath the surface of Mars, and/or Europa, and/or Enceladus to—that protected environment, where there's liquid water on Europa and Enceladus, and where there might be aquifers on Mars. That would be the one thing I would advocate for.

Chairman BEYER. Well, thank you all very much. This is definitely the most fun Science Committee hearing we've had since the folks who discovered gravitational waves came and spoke to us. And much more fun than Andy Weir, actually, so—so we hope we'll have you back. We look forward to all the progress you're going to make, not just on Perseverance or Mars Sample Return, but for humanity, because you really do inspire everything else that we do, so we're very, very grateful.

And let me finish with the official closing. Before we bring this hearing to a close, I want to thank our witnesses, of course. The record will remain open for 2 weeks for additional statements from the Members, and for any additional questions the Committee may ask of the witnesses. So, with that, you are excused, lunchtime, the hearing is now adjourned, and thank you very much.

[Whereupon, at 12:35 p.m., the Subcommittee was adjourned.]

Appendix

Answers to Post-Hearing Questions

ANSWERS TO POST-HEARING QUESTIONS

Responses by Dr. Michael A. Meyer

NASA Responses to
Questions for the Record for the
House Committee on Science, Space, and Technology
Subcommittee on Space and Aeronautics
Hearing
"What Do Scientists Hope to Learn with NASA's Mars Perseverance Rover?"
(Dr. Michael A. Meyer)
April 29, 2021

1. **During the question and answer portion of the hearing, you mentioned that discussions were underway now about the requirements and considerations for a facility to analyze the samples collected by Perseverance and eventually returned to Earth. Could you please expand on your comments during the hearing, and describe the process for determining the requirements for such a facility, who is involved in that process, and the notional timeline for the eventual facility?**

The joint NASA and European Space Agency (ESA) Statement of Intent recognizes a facility on U.S. soil under international management for samples returned from Mars. NASA and ESA have begun the process of developing the science requirements for a facility needed to simultaneously handle Astromaterials and BioSafety Level-4 (BSL-4)-type samples. The requirements for such a facility will be governed by a combination of science requirements suggested by the Mars Sample Return Science Planning Group – Phase 2 (MSPG2), any recommendations adopted by NASA from the Committee on Space Research (COSPAR)-sponsored international group looking at Sample Safety Assessment Protocol for Planetary Protection, and existing national and local regulations. In addition, the White House interagency study for a *National Strategy for Planetary Protection* will produce policy that may have specific ramifications for a Mars sample receiving facility. The MSPG2 document finalization presented at the end of June developed a working list of requirements.

NASA and ESA are in the initial phases of planning a facility. Yet to be fully considered are the MSPG2 recommendations and a NASA-ESA joint study, after which trade studies of the design options will be conducted.

NASA expects trade studies to be conducted in 2022. Since the schedule for a facility likely will differ depending on the approach (rent, brick and mortar, modular, or a hybrid approach), NASA is not able to provide a timeline.

2. **We have been landing scientific missions on Mars for 45 years. In your oral testimony, you described how NASA's Mars science strategy has evolved from following the water up through today's objective of sample return. Why is now, in particular, the right time to collect a sample from Mars and bring it back to Earth to study? Is it that the technology was not ready until now, or have we reached the point in the science where a sample is the next logical step?**

The answer to the question "why now" is a combination of technological ability, infrastructure, willing partners, and a scientifically robust approach promising to acquire the most informative samples. Sample return is the next step in Mars exploration as delineated in the Exobiology Strategy for Mars Exploration (1995), An Astrobiology Strategy for the Exploration of Mars (2007), and both Planetary Science Decadal Surveys by the National Academies of Sciences, Engineering, and Medicine.

NASA's previous missions to Mars have greatly improved our understanding and technological capability. We know where to find the most promising samples on Mars – ones that are most apt to answer fundamental questions that cannot be answered from orbit or by landers on the surface.

Even with a theoretical laboratory-on-a-chip, there would still be instrumentation that cannot fit onto a spacecraft, the inability to minutely manipulate samples for specific analyses, and the lack of opportunity for multiple (and potentially unanticipated) lines of investigation. The opportunities for investigation are not just at the initial arrival of samples on Earth, but for generations into the future.

Technological advances have made sample return easier, such as the capability to execute the pinpoint landing that made landing in Jezero crater feasible, and to be able to split between spacecraft the duties of sample caching, sample fetching, and a Mars Ascent Vehicle.

3. **More international space agencies are developing capabilities to get to Mars; scientific spacecraft from both the United Arab Emirates and China also arrived at Mars this year. Are there potential considerations for NASA to partner on Mars scientific exploration with entities beyond ESA?**

   o **All of NASA's scientific data is freely available to the public. To what extent will scientific data collected from the non-NASA Mars probes be shared openly with the scientific community?**

There are concepts to partner with entities other than ESA. A good example is the NASA collaboration on the Japan Aerospace Exploration Agency's (JAXA's) Mars Moons Exploration (MMX) mission. MMX is in development by JAXA, and NASA is supporting the development of one of the spacecraft's suite of seven science instruments.

NASA science mission data are publicly available, and when considering whether to partner on science missions with other entities, NASA takes into account the availability of science data. In the case of missions in which NASA is not involved, public data availability will depend on the policies of the space agency in question. For instance, ESA has a Planetary Science Archive, a public archive analogous to NASA's Planetary Data System, that is available to researchers worldwide.

Responses by Dr. Bethany L. Ehlmann

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

SUBCOMMITTEE ON SPACE AND AERONAUTICS

What Do Scientists Hope to Learn with NASA's Mars Perseverance Rover?

Questions for the Record to: Dr. Bethany L. Ehlmann

Submitted by Chairman Beyer

Replied to by Dr. Bethany Ehlmann

June 30, 2021

Dear Chairman Beyer:

Thank you for the opportunity to testify. I include below my replies to questions for the record, embedded below each question. Please do reach out if I can provide any additional information.

Best regards,

Bethany Ehlmann

1. You noted, in response to my question during the hearing about the possibility of terraforming Mars, that Perseverance would not be able to answer whether the solid ice we now know is on Mars, particularly on the poles and under the surface, ever melts naturally. In addition, you noted that you would like to answer that question and whether modern life may be associated with that ice before we send humans to Mars. Do you think we are on a path to be able to answer those questions before humans begin to explore Mars, estimated to be as early as the 2030s? If not, what might be needed to do so?

The big questions about ice on Mars—where is it? does it ever melt? could it be inhabited by Martian microbes?—will not be answered by the Perseverance rover because there is not ice on Mars today near the equator, where Perseverance explores and sample-collects ancient rocks.

Questions about Mars ice can be answered by exploration from the poles to the mid-latitudes. We know now that there is ice on Mars near the surface, at least patchily, as far south as 37°N[1]. This is about the latitude of San Francisco or Washington, DC. With Mars' changing climate over the last million years[2], the ice might melt. We want to address the is-there-modern-life-on-Mars question now, before we have to worry about "discovering" the terrestrial microbiome on Mars. Ice is also a crucial resource for human explorers.

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[1] Morgan, G. et al., 2021, Availability of subsurface water-ice resources in the northern mid-latitudes of Mars, *Nature Astronomy*, 5, doi: 10.1038/s41550-020-01290-z

[2] Buhler, P.B. et al., 2020, Coevolution of Mars's atmosphere and massive south polar CO2 ice deposit, *Nature Astronomy*, 4, pages364–371, doi: 10.1038/s41550-019-0976-8

Answering “where is the ice?” requires much better ice mapping from orbit than we have now. My understanding is that NASA is planning a Mars Ice Mapper (MIM) mission, targeted for 2028 launch, that is paid for by NASA HEOMD and implemented by NASA SMD (Planetary Science Division) with extensive international contributions for a cost-effective implementation[3]. MIM would carry a radar intended for mapping of ice in the upper meter of the surface at fine spatial scale. Determining the amount and distribution of near-subsurface ice on Mars is a priority science objective related to understanding Mars’ climate that simultaneously addresses a priority for human exploration. I am excited by the potential of the MIM mission and its timing is appropriate, but I believe there is a need for greater coordination between the human exploration planners and the science community, as also highlighted at the recent Mars Exploration Program Analysis Group (MEPAG) meeting by the MEPAG chair.[4] In particular, the performance capabilities of the presently-formulated radar might not enable HEOMD to achieve stated mission objectives for sensing depth due to the near-surface scattering properties of Mars at the proposed wavelength, which is significantly shorter (higher frequency) than the wavelength chosen by multiple recent NASA-funded Mission Concept Studies that include radar for near-surface ice studies[5]. NASA recently announced steps to deepen engagement with the science community experienced in radar remote sensing of Mars as well as openness to improved payload systems[3]. I am thus hopeful that the MIM mission is on track and that the concept can be refined to provide excellent data on ice distribution on Mars, in service of human exploration and making progress toward science objectives, before the early 2030s.

Answering the questions “does the ice melt?” and “is the ice inhabited?” cannot be done from orbit but requires a landed mission. Without action now, this will not be accomplished before the early 2030s. While China has plans to send multiple missions to the Mars surface in the next 10-15 years, at present, NASA does not have another scheduled landed mission to Mars after Mars Sample Return. The Mars Architecture Strategy Working Group (MASWG) recently highlighted the importance of continuing landed missions as part of the Mars Exploration Program, including Mars ice *in situ* explorers, implementable at different price-points[6]. To receive data by the early 2030s, a landed mission focused on looking for modern life in ice or investigating the physical and chemical properties of ice and whether it melts would need to start on a path of steady development by the mid-2020s. Such an exciting mission is a ripe opportunity for further collaboration between human exploration and scientific robotic exploration to answer questions about Mars ice and Mars life.

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[3] Ianson, E et al., Mars Exploration Program Analysis Group Meeting (MEPAG), 21 June 2021. https://mepag.jpl.nasa.gov/meeting/2021-06/03_MIM_MEPAG_Presentation_%2021_JUN_2021.pdf

[4] Yingst, A et al., Mars Exploration Program Analysis Group Meeting (MEPAG), 21 June 2021. https://mepag.jpl.nasa.gov/meeting/2021-06/03_MIM_MEPAG_Presentation_%2021_JUN_2021.pdf

[5] Calvin, WM et al., 2021, The Mars Orbiter for Resources, Ices, and Environments (MORIE) Science Goals and Instrument Trades in Radar, Imaging, and Spectroscopy, *The Planetary Science Journal*, 276, doi:10.3847/PSJ/abe4db | Calvin, W. M., et al. 2020, Mars Orbiter for Resources, Ices, and Environments (MORIE) (Washington, DC: NASA), https://science.nasa.gov/science-red/s3fs-public/atoms/files/Mars%20MORIE.pdf | Lillis, R. et al. 2020, Mars Orbiters for Surface-Atmosphere-Ionosphere Connections, https://science.nasa.gov/science-red/s3fs-public/atoms/files/Mars%20MOSAIC.pdf

[6] Mars Architecture Strategy Working Group (MASWG), Jakosky, B. M., et al. (2020). Mars, the Nearest Habitable World—A Comprehensive Program for Future Mars Exploration. https://mepag.jpl.nasa.gov/reports/MASWG%20NASA%20Final%20Report%202020.pdf

2. What has been your experience on the science team for Perseverance? How do you have to prioritize your time between analyzing new data as it is received, strategizing for science activities during the next sol, and actually operating the rover and the instruments? How has the experience for you been different under the constraints of COVID?

I have had the privilege of working on the Mars Exploration Rovers (Spirit, Opportunity) and the Mars Science Laboratory (Curiosity) before Mars-2020 Perseverance. COVID has made the experience of Perseverance quite different, requiring a substantial amount of human perseverance! On these other rover missions, we got to meet in-person to practice operations several times before landing and then, once successfully on Mars, and go through the learning curve of new tools and new procedures and challenging debates and decisions of science prioritization together, in the same room, where we could help one another learn as well as talk informally to build a team consensus. With Perseverance, I have not met many of the people that I interact with on an operations shift to plan the science of the day. COVID makes it slower to learn, a bit slower to explore, and somewhat more challenging to get a sense of the room and build consensus. It made getting the pre-landing, on-Earth rover testbed sequence runs that we need before performing first-time activities on Mars slow going. But we have gone forward as a Perseverance missions successfully, thanks to the leadership of the project and the courage and dedication of individual team members. For each person and indeed each mission, the balance between day-of quick data analysis, tactical operations, and long-term data analysis and strategizing is different. For me, I work downlink data analysis for Mastcam-Z. For one of my students, she works mostly tactical uplink for Mastcam-Z and SHERLOC. Both of us also do laboratory data analysis and orbital data analysis to complement and extend the data from the rover and fold into long-term decisions about our traverse path. It is a continual juggling of priorities between the short-term and long-term on a rover mission, but that is part of what makes it exciting: setting the goalposts on the horizon and then working together over the years to make the goal.

3. You were involved in the science community's landing site selection activities for Perseverance. With Perseverance now on Mars, we know exactly where in Jezero Crater the rover ended up and have a chance to look around. How does the actual landing site and its surroundings compare to predictions and view from a distance?

We knew from prior Mars Exploration Program orbital data that Jezero crater was going to be a good site: we were going to be landing in an ancient lake basin with lake floor sediments, exposed for exploration. That is indeed what we have found, preserved, for example, in the spectacular Kodiak butte, shown in the images that I presented in my testimony. We knew that we would see hydrous minerals formed in past liquid water as well as rocks enriched in volcanic minerals olivine and pyroxene that might not have seen much water. We have found these on the ground too. The remote sensing from orbit was right in steering us to a spectacular spot at Jezero.

Now that we are on the ground, we are able to address questions that were simply unanswerable from orbit. We are making the measurements right now that determine did the water-formed minerals form in a long-lived Lake Jezero or are they older, washed in from terrains upstream? What are these olivine-rich units we see—a product of widespread lava, volcanic ash from a giant explosive eruption, or huge impacts? And, importantly, did this lake once host organic matter that could sustain life or be, in fact, evidence of life? With orbital data, we come to the ground with much better questions, and we know exactly which rock outcrops to drive up to and find our answers. And with Mars 2020 we have the benefit of collecting the best rocks to bring back to our labs on Earth to analysis via Mars Sample Return. Mars only gets more interesting, the closer we are able to take a look. Stemming from the missions of the Mars Exploration Program, we have spotted many dozens more distinct places and environments from orbit. I look forward to more rover wheels—or boots – on the ground at Mars to explore.

Responses by Dr. Luther Beegle

Q1: What has been your experience on the science team for Perseverance? How do you have to prioritize your time between analyzing new data as it is received, strategizing for science activities during the next sol, and actually operating the rover and the instruments? How has the experience for you been different under the constraints of COVID?

A1: This is an excellent series of questions. My experience with the science team has been largely excellent. We have a team of over 500 scientists and engineers working operations, and the interactions have largely been very positive. When I think about the interactions within the science team and the effects of COVID, they are interrelated. The best way to expound upon this is to compare the experiences between working operations for the *Perseverance* and *Curiosity* rovers.

At the time, *Curiosity* was the most complex robotic space craft ever flown. All the commanding of the hardware had to be developed, validated, and tested before it could be used on the rover, and much of that process was done after landing. For the first 90 sols (a martian day, roughly 24.6 hours long) the entire team was collocated at JPL and worked on Mars time. The entire team worked 12 hour shifts which started and ended at all hours of the day and night depending on the local rover time. During operations, there is a lot of down time for individuals while developing the daily plan. Informal hall way type discussions were the norm. On *Curiosity*, the team developed an *esprit de corps* that was inspirational. Everyone experienced how hard other teams were working. Everyone asked probing questions to figure out how the different rover systems operated. Everyone developed a deep understanding on how instruments worked and made measurements. *Curiosity* has been operating for 9 years. Operations for that spacecraft have become almost routine, at least routine for operating a rover on Mars.

Perseverance has a lot of similarities with *Curiosity* in many ways but it is also more complex. Additionally, it has a different payload, with vastly different instruments that make measurements that have never been attempted on mars before. There is a large learning curve with all aspects of *Perseverance*. When operations take place over the internet, the little conversations that happened in the halls and during down time do not happen. When down time happen, events such as dinner with family members, the writing of email occurred or a million other distractions were present. This has resulted in a science and operations team that is not as connected as they were *Curiosity*. Also, memory of how hard operations were in the early days of *Curiosity* have been replaced with the routine of operational nature that the rover is currently experiencing.

While I don't think it will adversely affect the scientific output of the mission, there is a tension that persists within the team that I think can be attributed to the constraints of COVID. Hopefully over the course of the next few years, this will change.

A typical team member works multiple daily shifts per month on rover operations. These are scheduled and planned out weeks in advance, so that researchers can allocate their time. Shifts are on average 10 hours a day, and currently include weekend operations. Most researchers have other obligations and can plan their time to handle their duties given the coordinated effort that goes into operations. Standalone science discussions occur every weekday. These discussions include hypothesis that individuals put forward, science results from pervious sols and where to drive to next. Meetings for discussing science occur every weekday.

Operations tasks are divided into four different flavors.

The first flavor is downlink where information coming back from mars is analyzed and discussed. A series of questions are put forward during this task. Did all the activities go as planned? What is the current state of the rover? Is the rover's power level as predicted? How much data is on the rover and how much more can we collect? If there is an anomaly, it is characterized and mitigations are developed when needed. During the first few months anomalies occurred fairly regularly, as we figured out how the instruments and rover worked on Mars. Mars throws a lot of curve balls and sometimes does not cooperate. An example of an anomaly is with instrument heating. During one operation, SHERLOC faulted out because it got too hot. We had programed the warm up heaters to come on but they were on for too long and caused the instrument to exceed allowable operational temperature. The automated fault protection detected this and the instrument was safe, but no data was collected on that sol. For the next sol, we adjusted these heat-to-use parameters accordingly, and everything went very smoothly.

The second flavor of operations is long term planning of operations. This group looks out over several months, and considers long term mission goals, including balancing in situ science and acquisition of samples for sample return. The current long-term plan is called the green zone campaign and has well defined science and engineering goals. It will take us to close to the end of the year, at which time we will have another group of long-term plans.

The third flavor of operations is strategic planning which looks out over the next week to determine how different resources are utilized. This includes the resources that have constraints such as rover power, data volume and rover operational times. Strategic planning considers what operations are possible for a particular sol, and determines how resources used on a sol affect other sols. For example, in order to use SHERLOC, we have to get a target in a particular spot in front of the rover where the robotic arm can reach it. In order to do that, the rover needs to move to that location. The longer the rover drives the more uncertain we are of the final location so a "bump" sol is usually bookkept in case we are off by a few meters. Therefore, whenever we want to analyze or acquire a sample we plan for two days of rover driving in order to get to a specific target. During these drives we plan to do other science measurements depending on how much power is available, so the strategic plan includes these science activities. If we don't require a "bump" we move up the analysis sol, and the strategic plan gets reconfigured. When ever we have the resources of time ad power, we use them.

The last flavor of operations is tactical, which is where the detailed plans are developed for a particular sol. These include the exact programing of the rover (i.e. move robotic arm to this position, fire the laser 100 times, take 3 images in a direction with MastCam-Z etc.). For this "sol plan", power, data volume and number of activities are clearly understood so that instrument analysis is fine tuned to maximized science return.

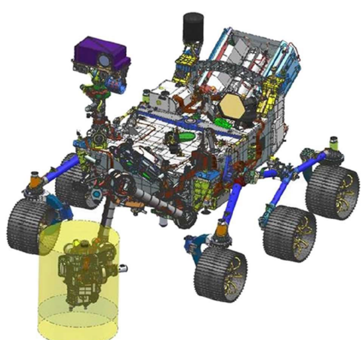
Prioritizing my time has been something that has been more difficult. During development, I was able to juggle SHERLOC, other work commitments and home life pretty well. I could set meeting times for all my responsibilities and plan my time so that I could have time for all my responsibilities. This included participating in my sons' high school robotic competitions, my daughters budding middle school acting career and events with my wife. However, every time we use SHERLOC on the surface it has been the first time we have done something, and that is something that I have been waiting to do for 10 years. I tend to want to be a part of everything to make sure it goes smoothly. To add to the stress is that most operations are done from home, the same place that down time is supposed to take place. So, every time I want to relax and watch a game or movie, I am doing so at my work location. This has really undercut the effectiveness of down time, and my ability to prioritize what to do next and to meet deadlines.

Q2. The instrument you lead, Scanning Habitable Environments with Raman & Luminescence for Organics & Chemicals (SHERLOC), is on the robotic arm of the rover. How much reach and dexterity does that robotic arm have, and how does the degree of dexterity affect the science that can be conducted? How does Perseverance's robotic arm compare to the arm on the last rover, Curiosity? How does it compare to what an actual human astronaut might be able to do? o What key innovations does SHERLOC incorporate and how do they advance our science capabilities on Mars?

A2: The main difference between the arm on *Curiosity* and *Perseverance* is the mass and size of the turret. On *Curiosity* the turret was 550 mm in diameter with a mass of 30 kg (66 lbs), while the turret on *Perseverance* is 750 mm in diameter and has a mass of 40 kg. (88 lbs).

The robotic arm on *Perseverance* is 2.5 meters in length and has 5 degrees of freedom including the turret rotation. The magic cylinder (see figure) is the area that is the optimum space in front of the rover in which we analyze and collect samples. It is roughly 1.2 m in front of the rover, and is 0.8 meters in diameter, and 1 meter tall. Within this magic cylinder, the arm can get us to within 1 cm (~0.4 inch) in each of three dimensions. Outside the cylinder the error increases. We designed SHERLOC to function within this arm placement uncertainty within the magic cylinder including an autofocusing capability and an internal scanning mirror that does not require arm movement.

The main constraint as to what we can do scientifically is the geologic formation we are studying. With a turret diameter of 750 mm (~30 inches), there are some targets we simply cannot reach with SHERLOC because the arm cannot place us in the proper location of 48 mm (2 inches) above the target due to rock shape and size. PIXL has more stringent constraints. Not being able to reach a target has not been an issue yet, and we don't expect it to happen more than a hand full of times given the most likely geologic context of the site we are exploring.



The advantage the human has over the robotic arm would be the ability to get into tight locations, such as over hangs in outcrops. The arm has several advantages over a human in that it can hold us much accurately over the 2 hours that it takes to make a measurement. The arm does move due to temperature changes over the course of a measurements but that is on order of a few 100 microns which is much less than if a human was holding it. We did specifically design the instrument to work on the arm with its known attributes. If we were building it for a human mission, we would have created an instrument deployment device that would resemble a tripod for stability.

Responses by Dr. Tanja Bosak

House Committee on Science, Space, and Technology - Subcommittee on Space and Aeronautics

Hearing Title: "What Do Scientists Hope to Learn with NASA's Mars Perseverance Rover?"

Date: April 29, 2021

Responses from Dr. Tanja Bosak to Chairman Beyer's QFRs

Compiled by Christine Joseph from email received by Dr. Bosak

1. Scientists have studied a few "samples" from Mars already: meteorites that have landed here on Earth. Why is it important for the Perseverance rover to collect samples from the Martian surface and bring them back to Earth? What do we hope to learn from returned samples that we could not learn from Martian meteorites?

We have a number of martian meteorites, but we don't get to pick the rocks that fall on Earth and don't know where on Mars any of these meteorites originated. If we want to look for early microbial life, we also need sedimentary rocks that have not been heavily altered by impacts or metamorphism. None of the current martian meteorites fit this requirement - all but one are igneous rocks (made by volcanic activity) and come from environments that would not have been conducive to life. Perseverance went to an environment that contained liquid water a long time ago and still contains sedimentary rocks that were deposited when water and habitable environments were present on Mars. By collecting these sedimentary rocks and rocks that can be dated upon return we get to actually look for evidence of past life, understand the causes for the climate change on Mars and ask why Mars lost its water.

2. You noted in your oral testimony that, if we detect any—or even no—evidence of microbial life in the samples Perseverance collects, "some of the findings that arise from the samples may even challenge our current interpretations of life—what life is, or how to detect it." What questions about life and its origins on Earth could returned Martian samples potentially answer? What current interpretations of life could be challenged by surprising findings in the returned sample analysis?

Samples of sedimentary rocks from Jezero crater will be older than any sedimentary rocks on Earth. By studying the martian samples, we can start asking what the conditions in habitable environments were before ~ 3.5 billion years ago. We simply don't have the terrestrial rocks that we could investigate in the same way - they've been eroded, metamorphosed or subducted. This will push the entire community to think hard about what we call life, what we accept as evidence for life, or whether life was transferred from Earth to Mars or from Mars to Earth. Even if we don't find any strong evidence for life (as in - microbial fossils or fossilized microbial mats), once we establish the ages of the returned samples, we can ask what conditions may have precluded the emergence of life on Mars. Currently, we don't really understand how many organic compounds were delivered to martian surface environments by comets and meteorites, how long it took for life to start, why the climate of Mars changed from warmer and wetter to the cold and dry, and how similar or different early Mars was from Earth.